BACK IN TIME HOW THE JAMES WEBB TELESCOPE IS CHANGING OUR UNIVERSE

COSMOS

THE SCIENCE OF EVERYTHING

Issue 96

COSMOS THE SCIENCE OF EVERYTHING

NEW WAYS OF SEEING

+

F1 meets *Top Gun* in our outback skies

Eyesight insight: vision goes quantum

Decoding the enigma of ancient nautilus

CAN A.I. MAKE ART?

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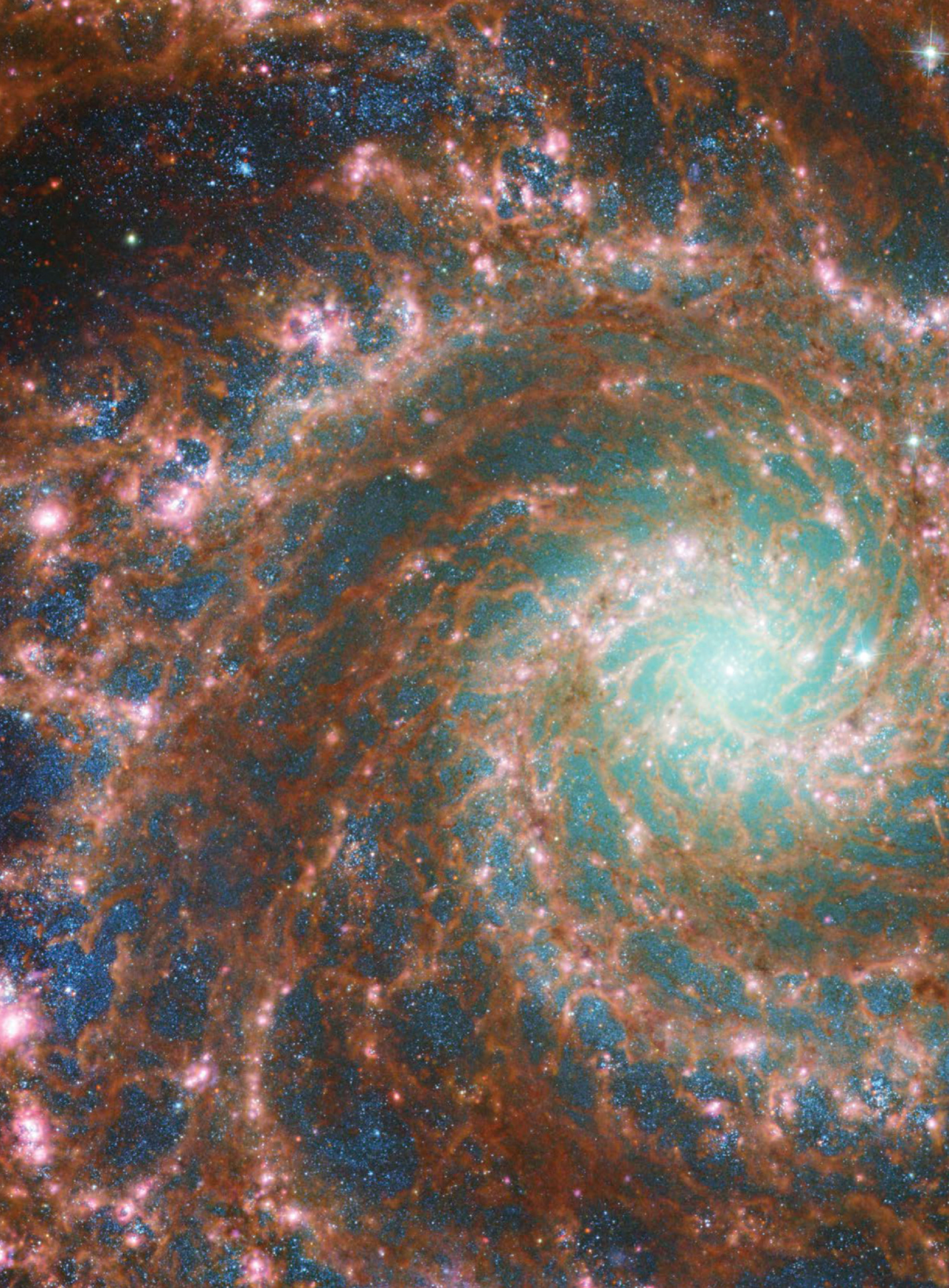
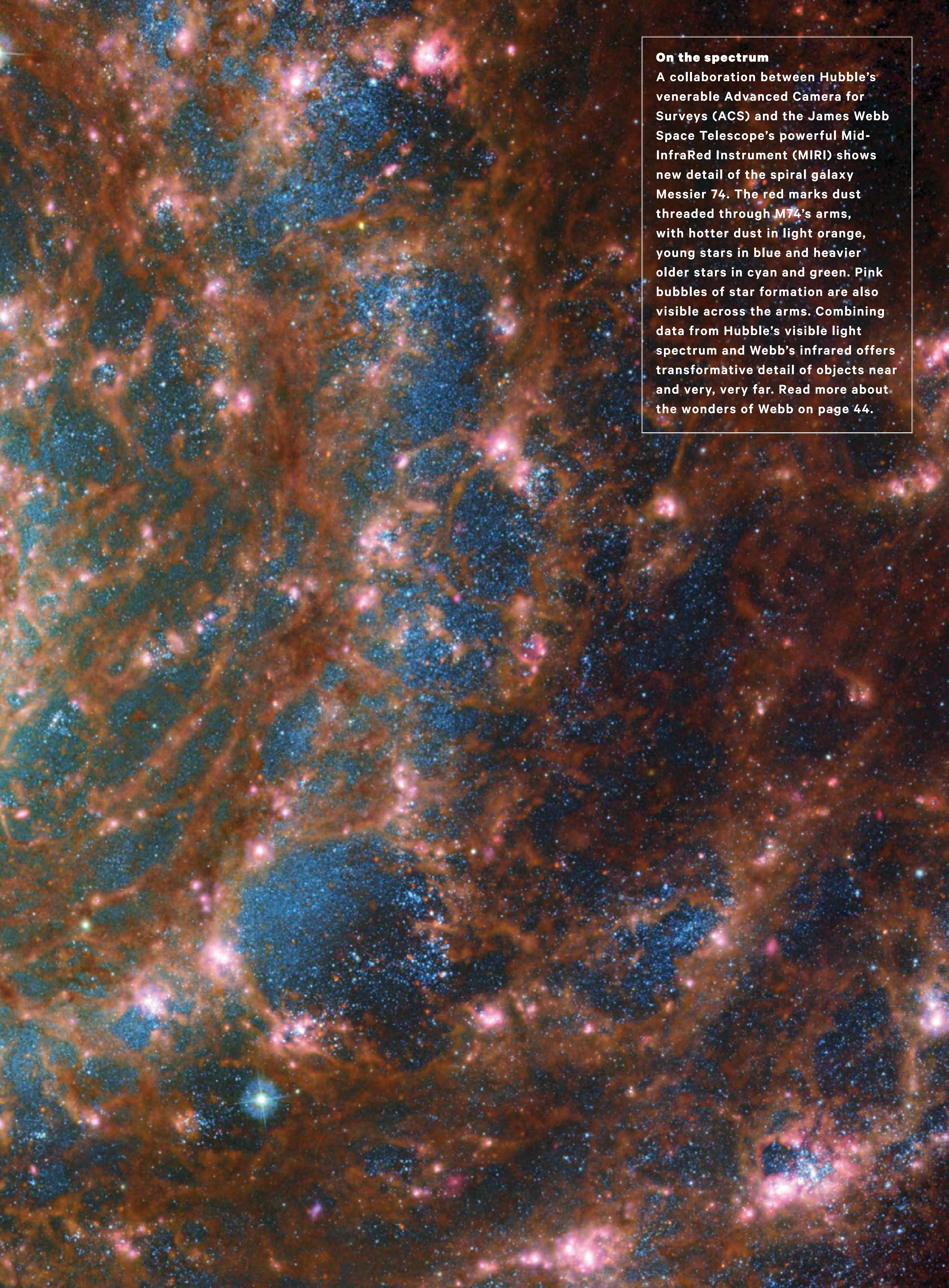
MAMMAL OF THE YEAR • BIRD GUIDE MASTER: TRADITION BEATS TECH • WHY WE YAWN





On the spectrum
A collaboration between Hubble's venerable Advanced Camera for Surveys (ACS) and the James Webb Space Telescope's powerful Mid-InfraRed Instrument (MIRI) shows new detail of the spiral galaxy Messier 74. The red marks dust threaded through M74's arms, with hotter dust in light orange, young stars in blue and heavier older stars in cyan and green. Pink bubbles of star formation are also visible across the arms. Combining data from Hubble's visible light spectrum and Webb's infrared offers transformative detail of objects near and very, very far. Read more about the wonders of Webb on page 44.

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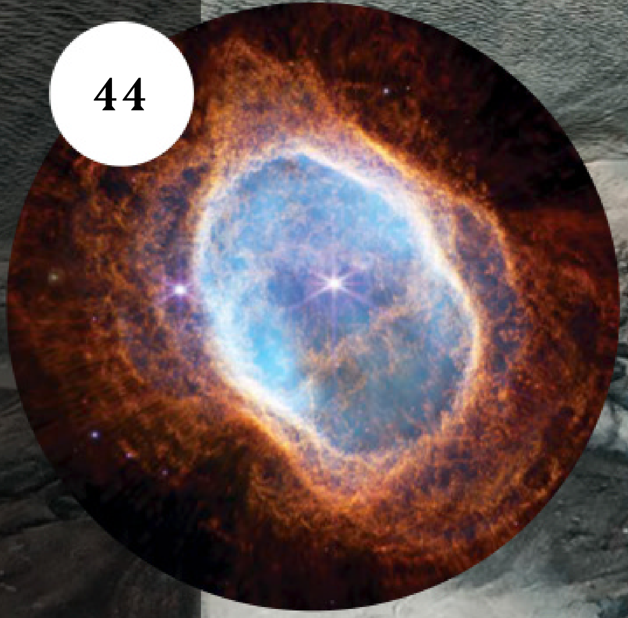

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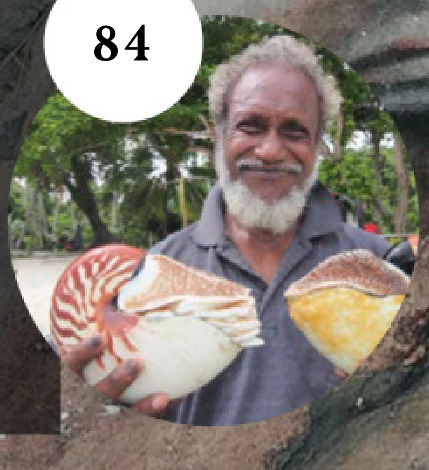

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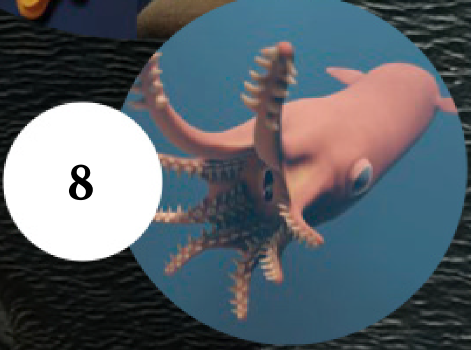
DAVID POPA



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David Popa's ephemeral "earth murals" are painted using pigments from the landscape and last only as long as low tide, temperature rise or the next storm. This piece – *Born of Nature II* – was created in Emäsalo, Finland. See more of Popa's work on page 62.

From the Designers

WHEN GAIL FIRST TOLD ME ABOUT MIDJOURNEY, I didn't suspect what she probably already knew; that here was an obsession just waiting to happen – to me.

As a piece of tech, it's very much in its infancy, much like the odd little robot child here that "Midge" and I rendered together after much prompting and re-rolling.

I admit, I'm torn. On the one hand MJ helps you create at a phenomenal rate. Which is exciting and fun and totally fine. On the other hand, within a few minutes I was able to generate works that were not dissimilar to the incredible creations of David Popa on page 62. And that is not fine. Popa is an *artist*. I'm not. The lengths to which he goes to express his talents must surely count for something.

Art Director Kate and I created this issue's cover using MJ and the prompt "retro color scheme sideways beautiful elegant 2d profile of face made of overlapping flowing magazine paper cut shapes with bird and nautilus". Kate directed, I interfaced with MJ and we arrived at the base image inside around 30 minutes, after which Kate worked her magic with the coverlines. Is it art? That's for you to decide. Turn to page 38 to read more about this terrible, tremendous, horrific, terrific advance in A.I.

GREG BARTON Designer
KATE TIMMS Art Director

[“robot child, ultra realistic, unreal engine, high resolution, 5d, hyperdimensional, volumetric lighting]

MIDJOURNEY

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From the Editors

AT ITS FINEST AND BRIGHTEST, science is all about seeing things in a new way – wondering "What if?" and then setting out to determine if it can be done, or if it's true. Proving something is the icing on the cake.

Surely nothing better underlines a new way of seeing and the joy of getting the engineering right than the James Webb Space Telescope (JWST). Since this extra-terrestrial visionary's first images went public we've found ourselves ditzy with anticipation for whatever comes next, a feeling shared by the writer of this issue's story about the JWST, astrophysicist Sara Webb.

There's no question that AI is providing researchers in many fields with useful new ways of seeing, but can it really create art? Evrim Yazgin set out to answer that question. (And sent our designers into a digital dreamland, see opposite.)

Sometimes a new way of seeing is staring us in the face, as Jacinta Bowler's investigation of what's known about vision (and what's not) proves. Is it possible that a single-celled organism has sight? And why do frogs have so many different pupil shapes?

Also this issue, Petra Stock introduces a former street artist who now literally paints on nature; Michael Archer and Christopher Telford consider the evolutionary reasons why we grind our teeth; Sophie Calabretto talks to the people behind a soon-to-be-true, *Star Wars*-style aerial racing competition; and Andrew Bain learns that illustrating a bird field guide is a craft that still leans on old ways, although an illustrator's main reference material is decidedly new.

The idiom "seeing is believing" doesn't always apply where science is concerned: no one's 'seen' gravity, after all. But science that's seen – let's again give a resounding cheer for the JWST and all who'll work with its data – has a special resonance. Revelation creates connection, and something tells us that the Webb telescope is going to build a new human relationship with the universe.

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DIGEST

Science news from around the globe

TECHNOLOGY

Google's protein-folding AI AlphaFold has nearly cracked all proteins

AlphaFold has just released 200 million protein structures, revealing the 'protein universe'.

The word 'breakthrough' is overused in scientific research, but occasionally something will be a breakthrough in the true sense of the word. For example, using CRISPR-Cas 9, mapping the human genome, taking the first image of a black hole – and now DeepMind's AlphaFold protein structure database.

For molecules that can be made up of only a couple of dozen different amino acids, proteins are incredibly complex. Each fold, twist and position can change how the protein works, so understanding these complicated 3D structures can tell us a lot about what the protein does.

Uncovering these multiple layers of structures is painstaking work. In the 1960s two Nobel Prizes were given for determining the structures of proteins, and in the early 2020s only 17% of the protein structures in the human body had been identified in a lab.

But DeepMind – an AI from Google's parent company Alphabet – has absolutely changed the game with AlphaFold.

"Determining the 3D structure of a protein used to take many months or years, it now takes seconds," says Eric Topol, founder and director of the Scripps Research Translational Institute. "AlphaFold has already accelerated and enabled massive discoveries, including cracking the structure of the nuclear pore complex.

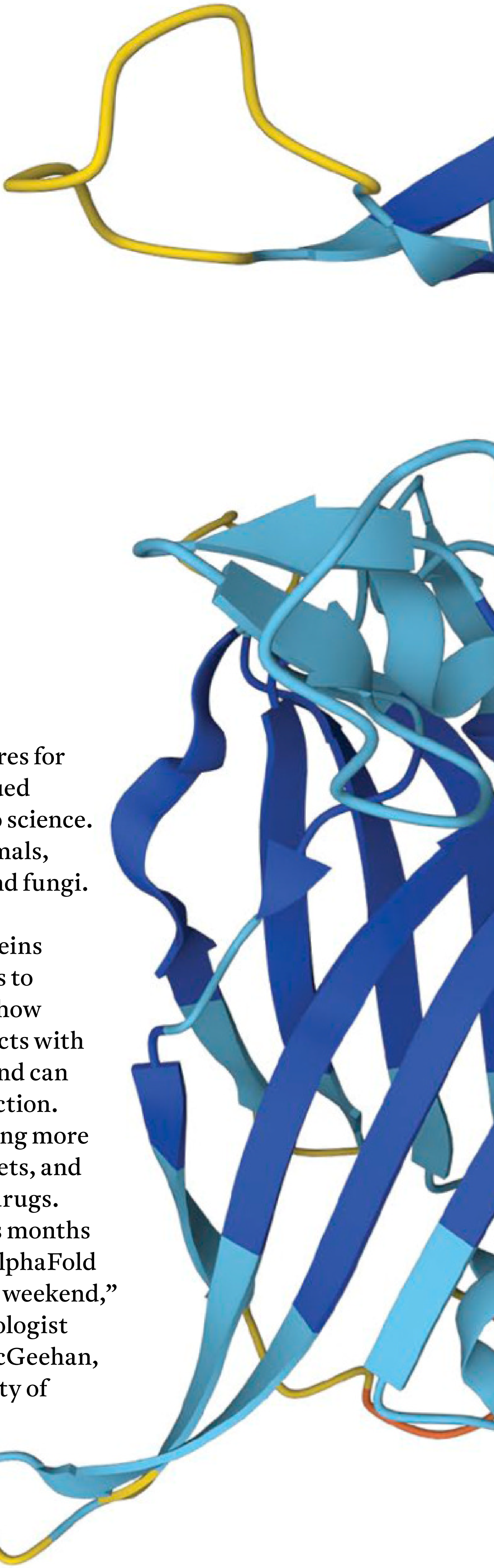
"And with this new addition of structures illuminating nearly the entire protein universe, we can expect more biological mysteries to be solved each day."

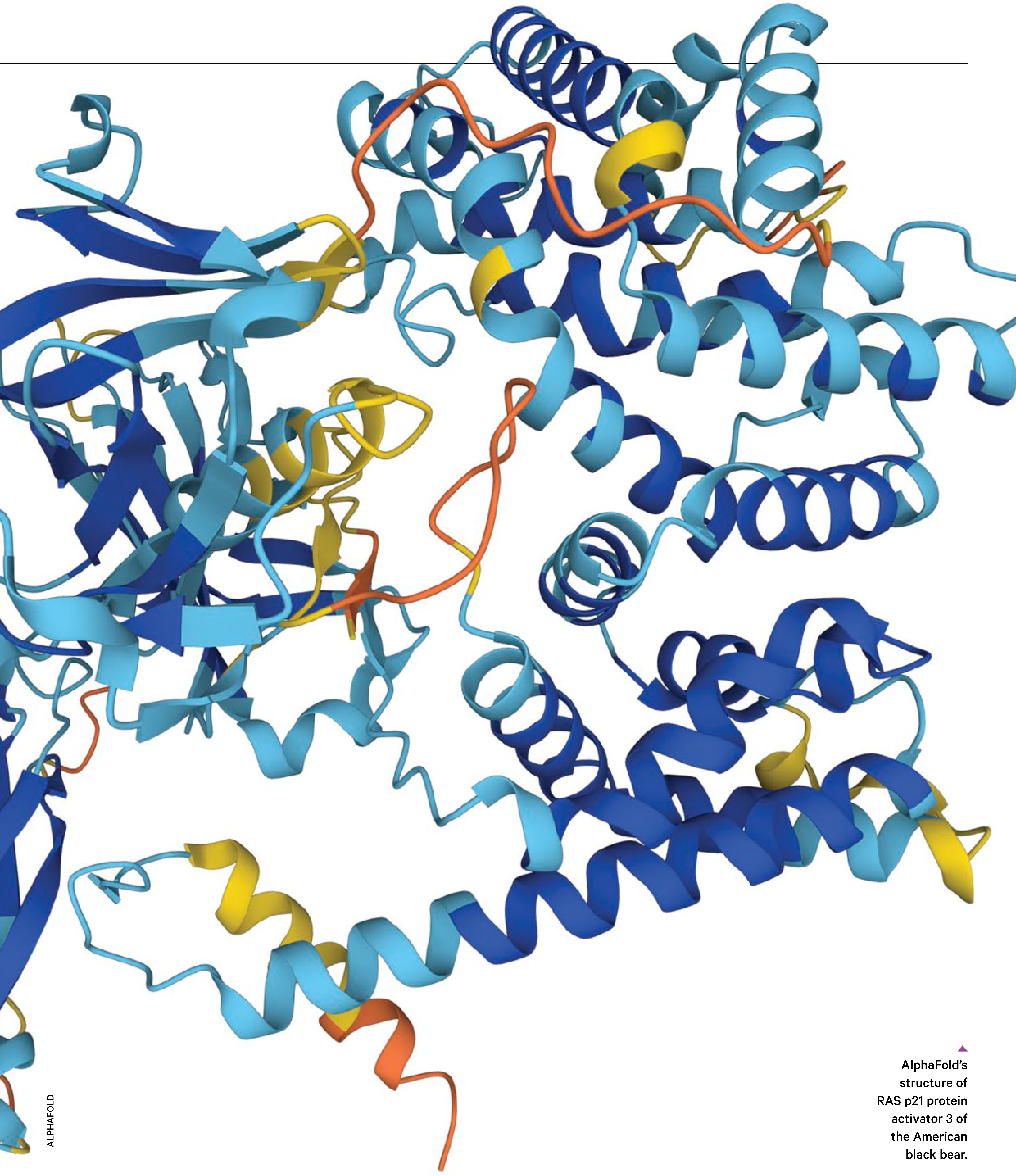
Over the past two years, AlphaFold has been dropping ever-larger numbers of protein structures into its database. In 2021 it was the entire human proteome, then hundreds of thousands of new protein structures, including the proteins for a number of human diseases.

Now the researchers have released 200 million protein structures – which is the predicted structures for nearly all catalogued proteins known to science. This includes animals, plants, bacteria and fungi.

Knowing the structures of proteins allows researchers to learn more about how the protein interacts with other molecules and can determine its function. This means creating more specific drug targets, and discovering new drugs.

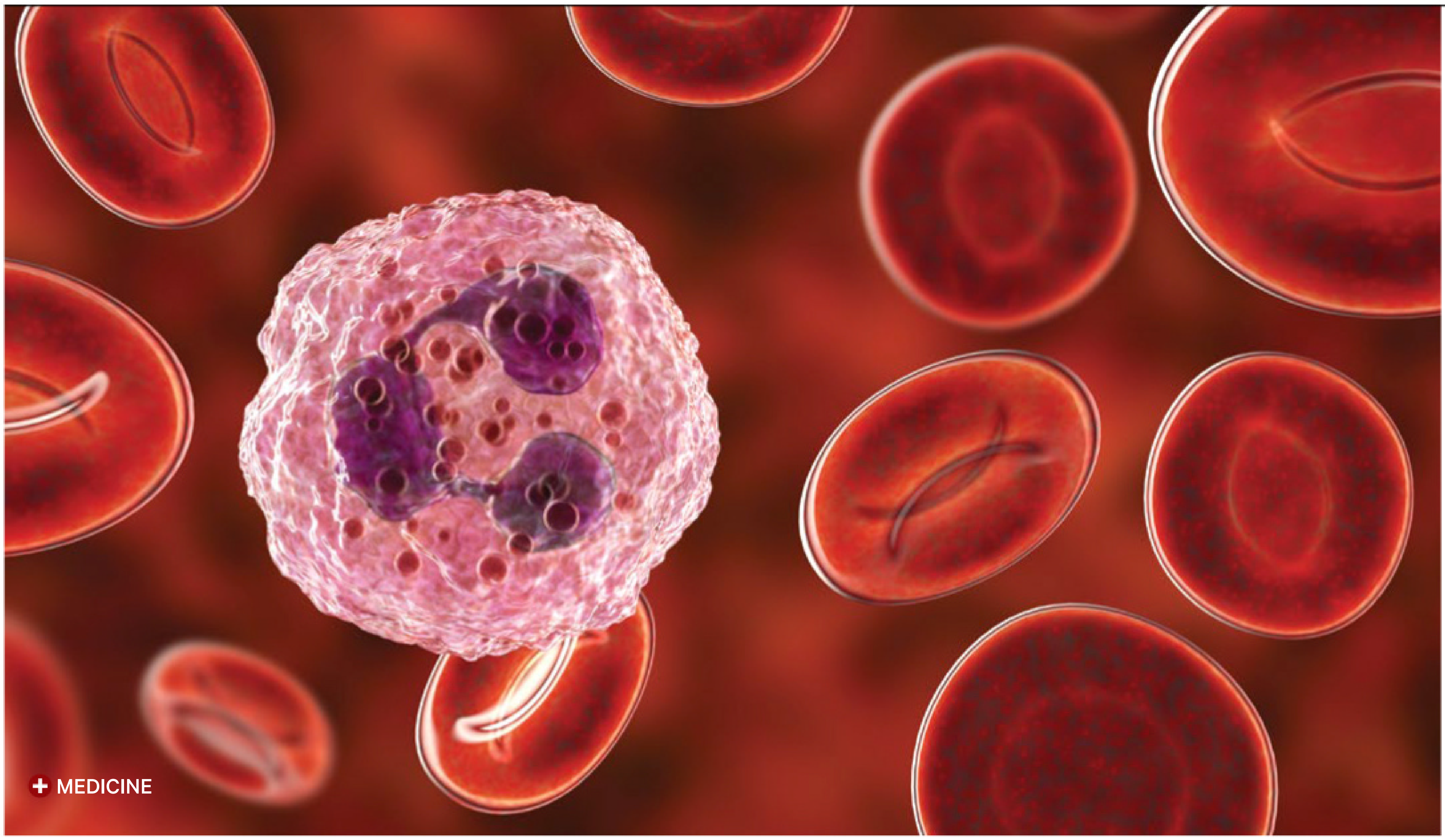
"What took us months and years to do, AlphaFold was able to do in a weekend," says structural biologist Professor John McGeehan, from the University of Portsmouth.





ALPHAFOLD

AlphaFold's structure of RAS p21 protein activator 3 of the American black bear.



MEDICINE

Turning white blood cells into medicinal microrobots with light

Neutrophils could one day be used to deliver drugs in the body.

Medicinal microrobots are currently being developed to allow doctors to better treat and prevent diseases.

Most of these are made with synthetic materials that trigger immune responses in small animals, causing them to be cleared from the body before they can do their job.

Now, scientists have reported for the first time their success using cells already present in the body – white blood cells called neutrophils – as natural, biocompatible microrobots in living fish.

The team used lasers to precisely control the neutrophils, or 'neutrobots', to perform multiple tasks – showing they could someday deliver drugs to precise locations in the body.

In a new study published in *ACS Central Science*, the authors write that the neutrobots "could hold great promise for the active execution of complex medical tasks in vivo, with great potential utility in the treatment of inflammatory diseases".

Instead of requiring injections or taking capsules to get the microrobot inside an animal or person, they propose using cells already present in the body as a less invasive alternative that won't set off the immune system.

"Unlike traditional medical microdevices, this neutrophil microcraft is free from artificial microstructures and invasive implantation processes, thus avoiding complicated preparation technology and tissue damage," the study authors say.

▲ Computer illustration of a neutrophil surrounded by red blood cells.

Neutrophils already naturally pick up nanoparticles and dead red blood cells, and can migrate through blood vessels into adjacent tissues, so they are good candidates for becoming microrobots.

It's been shown that neutrophils can be guided and moved around by lasers in lab dishes, but the researchers – from Jinan University, China – wanted to see if this approach would work inside living animals.

They manipulated and manoeuvred neutrophils in zebrafish tails, using focused laser beams as remote optical tweezers.

They found that the neutrobots could be moved up to 1.3 micrometres per second, which is three times faster than a neutrophil naturally moves.

The study, they say, advances the possibilities for targeted drug delivery and precise treatment of diseases.

KATERYNA KON / SCIENCE PHOTO LIBRARY / GETTY IMAGES

CHEMISTRY

A DISPOSABLE PAPER BATTERY THAT RUNS ON WATER

A few clever inks can make paper electric.

A team of Swiss researchers has made a disposable battery out of paper.

The paper battery, described in *Scientific Reports*, is printed with a couple of inks that perform the function of the battery. It's inert until you add a few drops of water, which allows ions to move between the inks and electricity to flow.

It's powerful enough to run a small LCD alarm clock, and it can run for an hour – two hours if it's dampened again. The battery is printed on a few square centimetres of paper. It uses two different inks as its anode and cathode: the anode ink is mostly zinc powder, while much of the cathode ink is graphite flakes. Both inks also have shellac, ethanol and polyethylene glycol in varying amounts to make them printable.

The anode and cathode inks are connected by a bridge of sodium chloride – table salt – in the middle. When dampened, the salt ions allow the anode and cathode inks to exchange positively and negatively charged particles, letting electrons flow through the wires.

EARTH

A good dose of salt calms the anger of the gods

Lightning doesn't have a taste for salt.

Research in *Nature Communications* suggests that coarse aerosols from sea spray reduce the frequency of lightning by 90% in tropical storms.

The team examined data from a large region of the tropics: between 50°W and 50°E, 20°N and 20°S, across the African continent and both adjacent oceans. They looked at lightning strikes from the World Wide Lightning Location Network alongside a range of other meteorological data over a five-year period from 2013 to 2017. They also examined aerosol concentrations using NASA's MERRA-2 dataset.

While fine aerosols (smaller than a micrometre) increased lightning frequency on both land and sea, coarse aerosols from sea spray had the opposite effect. Even when all the other weather and cloud conditions were similar, higher amounts of sea-spray aerosols reduced the frequency of lightning strikes.

In contrast, coarse aerosols that occur (more rarely) over land, such as those caused by desert dust, had a slight encouraging effect on lightning.

The researchers suggest the reason could be that the aerosols encourage fewer and bigger water droplets to form, which increases the amount of warm rain in a cloud. This means there are fewer ice crystals, which help clouds to electrify.

They add that tracking marine aerosols could allow meteorologists and climate scientists to make more accurate weather and climate predictions.

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BIOLOGY

DO ARACHNIDS DREAM OF INVERTEBRATE SHEEP?

Jumping spiders may have a REM-sleep-like state.

Similar to the active sleep of dreaming humans, jumping spiders (*Evarcha arcuata*) might have a rapid eye movement (REM) sleep-like state as well – according to new research in *PNAS*.

Researchers analysed nocturnal infrared footage of 34 juvenile jumping spiders and found that the spiderlings exhibited consistent periods of retinal movements at regular intervals, coinciding with body movements that are commonly associated with REM sleep in other animals.

"The combination of periodic limb twitches and eye movements during this sleep-like state, as well as the increase of duration of REM sleep-like bouts, meets core behavioural criteria of REM sleep observed in vertebrates, including humans," the authors say.

"Eye movement patterns during REM sleep have been hypothesised to be directly linked to the visual scene experienced while dreaming – begging the deeper question of whether jumping spiders may be experiencing visual dreams."

TECHNOLOGY

Australia's newest Cray supercomputer is online in Perth

Taking data from the Square Kilometre Array telescope is big business.

Australia's newest supercomputer is already providing science with exciting new opportunities.

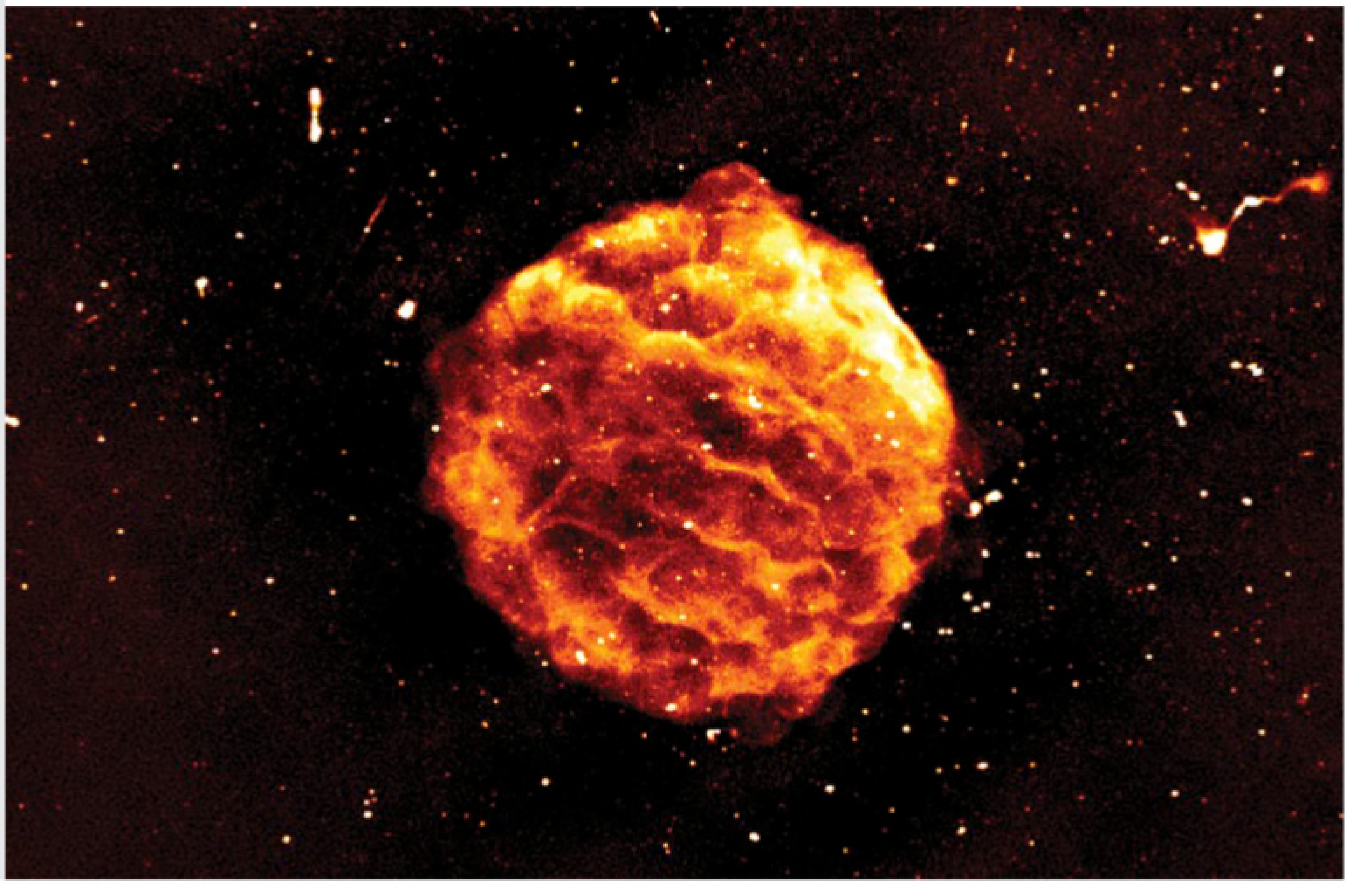
Named Setonix after *Setonix brachyurus* (the quokka) the supercomputer has produced a detailed image of a supernova remnant.

Data used to create the image were collected with CSIRO's ASKAP radio telescope at the Murchison Radio-astronomy Observatory in Western Australia, about 800 kilometres north of Perth, and transferred to the Pawsey Supercomputing Research Centre in Perth.

"Processing data from ASKAP's astronomy surveys is a great way to stress-test the Setonix system and see what is possible," says Dr Pascal Elahi, Pawsey's supercomputing applications specialist.

While Setonix is ramping up to full operations, so is ASKAP, which is currently wrapping up a series of pilot surveys and will soon undertake even larger and deeper surveys of the sky. Setonix will be used to process the data collected by ASKAP.

When fully operational, Setonix's eight cabinets will include 50 petaFLOPS of raw compute power, 548 terabytes of memory and consume 46 kilowatts per petaFLOPS – up to 30 times more powerful than Pawsey's earlier Galaxy and Magnus systems combined.



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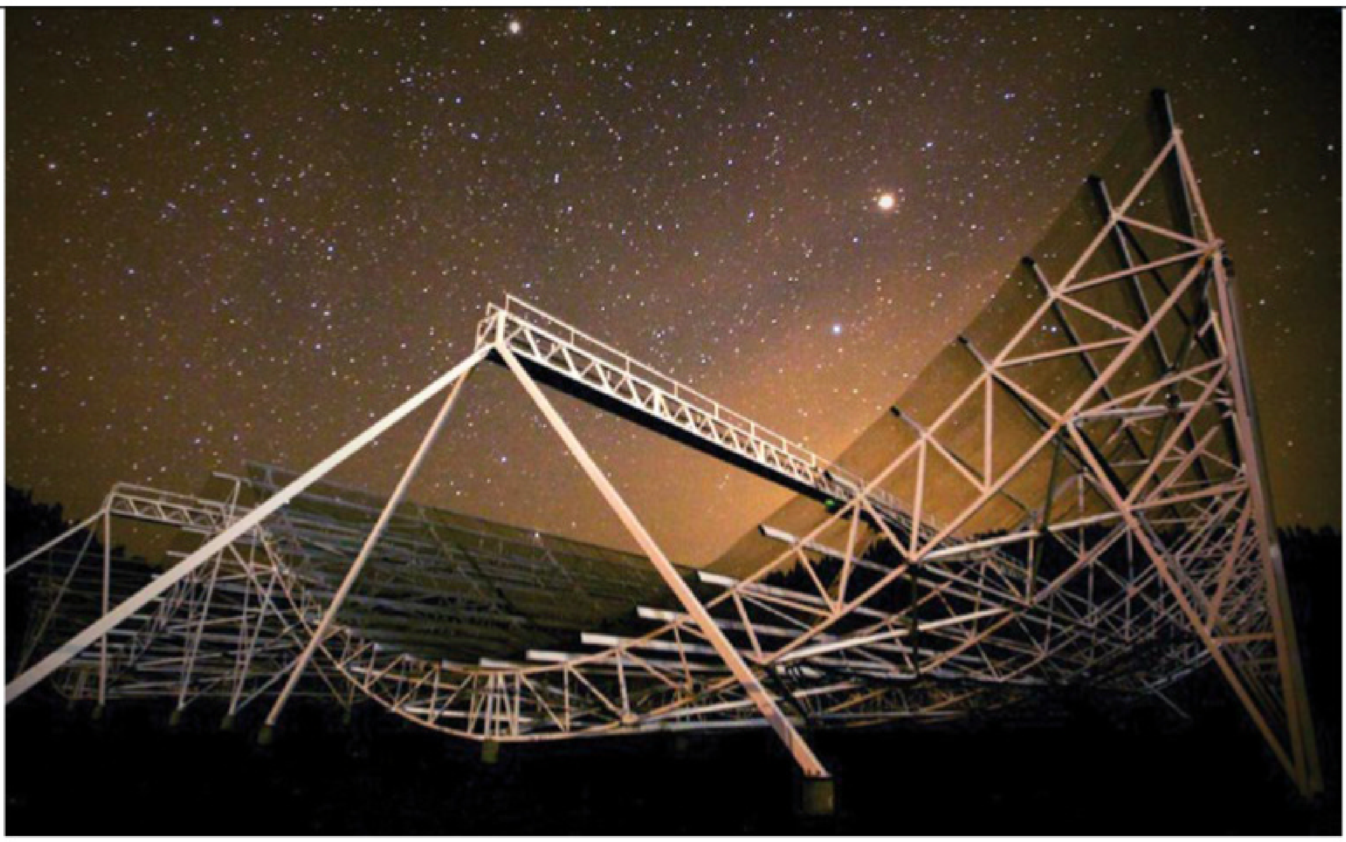


CHIME

SPACE

Cosmic 'heartbeat' detected in fast radio burst billions of light-years from Earth

The new FRB is the longest lasting with the clearest pattern known.

▲ The large radio telescope CHIME has picked up a rare regularly repeating fast radio burst.

Astronomers have detected a new fast radio burst, or FRB, from a galaxy far, far away. The new FRB is currently the longest lasting with the clearest periodic pattern ever observed.

FRBs are strong pulses of electromagnetic radiation in the radio-frequency end of the spectrum. The first FRB, known as the Lorimer burst, was detected in 2007, but their exact astrophysical origins still remain mysteries.

Typically, fast radio bursts last a few milliseconds at most, and either go quiet or, very rarely, repeat somewhat periodically. This new signal, however, is about three seconds long – about a thousand times longer than the average FRB – and contains a clear periodic pattern repeating every 0.2 seconds.

Labelled FRB 20191221A, the burst's source is in a galaxy several billion light-years from Earth and is theorised to be a neutron star like a radio pulsar or magnetar. The finding is described in a paper published in *Nature*.

"There are not many things in the universe that emit strictly periodic signals," says co-author Daniele Michilli, a postdoc in MIT's Kavli Institute for Astrophysics and Space Research, US.

"Examples that we know of in our own galaxy are radio pulsars and magnetars, which rotate and produce a beamed emission similar to a lighthouse. And we think this new signal could be a magnetar or pulsar on steroids."

FRBs have been detected across the universe. One instrument that has recently been finding radio bursts is the interferometric radio telescope Canadian Hydrogen Intensity Mapping Experiment, or CHIME.

As Earth has rotated, CHIME – which began observations in 2018 – has picked up radio waves emitted by hydrogen in the early universe as well as hundreds of FRBs.

Most of the bursts CHIME has found are fleeting and random in their construction. But, like a stethoscope on the universe's rib cage, on 21 December 2019 CHIME found a cosmic pulse.

"It was unusual," Michilli says. "Not only was it very long, lasting about three seconds, but there were periodic peaks that were remarkably precise, emitting every fraction of a second – boom, boom, boom – like a heartbeat. This is the first time the FRB signal itself is periodic."

The team analysed the signal and found similarities with pulsars and magnetars in our own galaxy – only the pulses from FRB 20191221A are more than a million times brighter. The researchers believe this means that the FRB may have come from a neutron star that is normally much less bright but ejected a series of magnificent bursts.

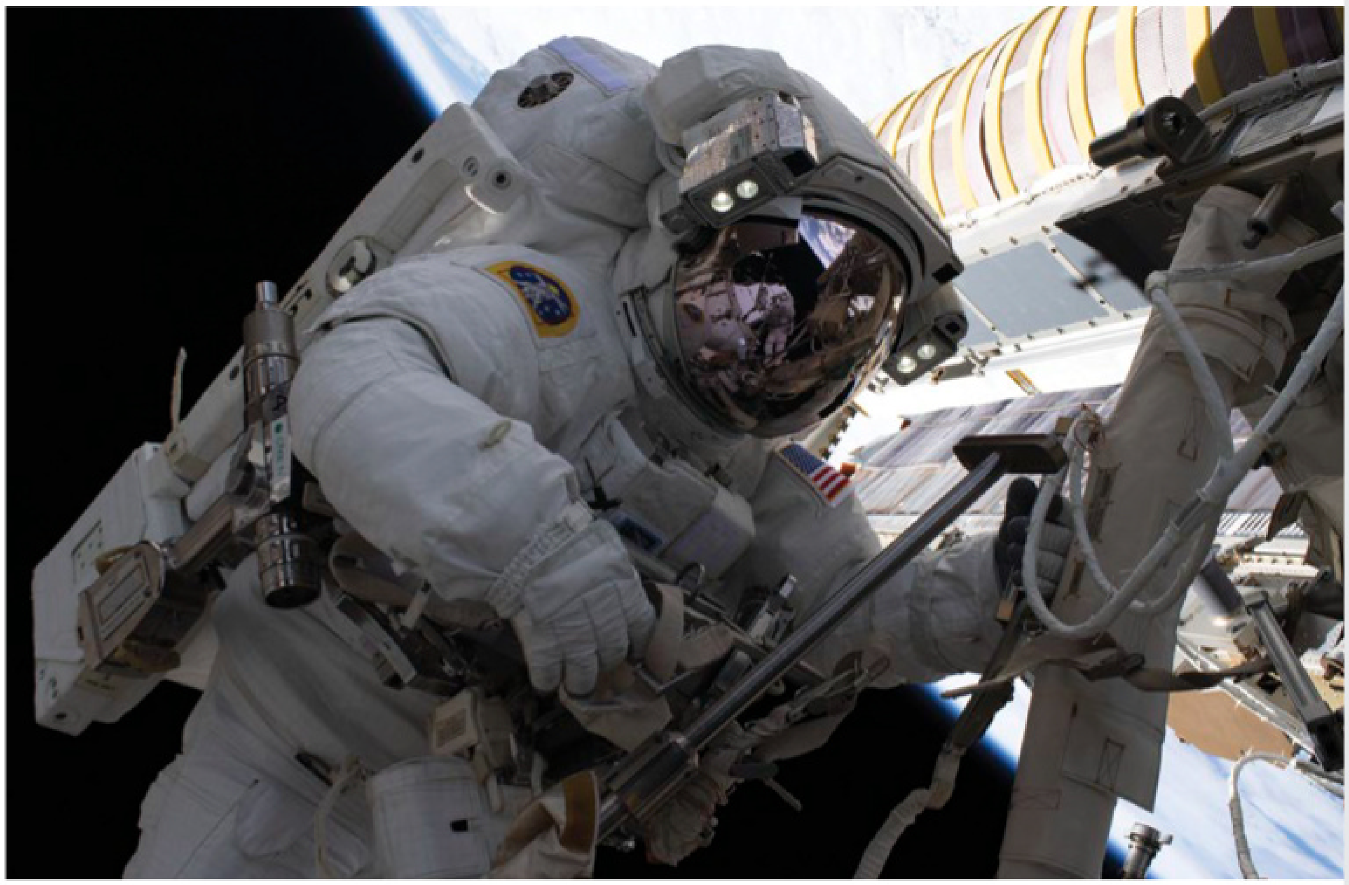
"From the properties of this new signal, we can say that around this source, there's a cloud of plasma that must be extremely turbulent," Michilli says.

If more pulses from FRB 20191221A can be seen in the future, it may help the researchers understand the source of the burst as well as neutron stars in general.

SPACE

Bone density doesn't bounce back

Six months in space is a decade on Earth.



▲ NASA astronaut Shane Kimbrough installing new roll-out solar arrays on the International Space Station's Port-6 truss structure in June 2021.

A year back on Earth is still not enough to recover from a few months of bone density loss in space, according to new research on 17 astronauts.

Living in zero gravity has a number of effects on the body, including a loss of bone density. A study published in *Scientific Reports* has found that this density usually isn't completely restored 12 months after four months (or more) in space.

"Bone loss happens in humans – as we age, get injured, or any scenario where we can't move the body, we lose bone," explains Dr Leigh Gabel, assistant professor in the Faculty of Kinesiology at the University of Calgary.

"Understanding what happens to astronauts and how they recover is incredibly rare."

Researchers scanned the tibia (shin) and radius (forearm) of 17 astronauts (three female, 14 male) before they went to space. They then did the same scans three times on their return: straight after, then six and 12 months after. The scans gave information about mineral density, resistance to fractures, and tissue thickness.

"This suggests the permanent bone loss due to spaceflight is about the same as a decade worth of age-related bone loss on Earth," says Gabel.

In better news for the spacefarers, some exercises during spaceflight seemed to mitigate this. Astronauts who stepped up their in-flight resistance training – deadlifting – were better at recovering bone mineral density in their shins.

BIOLOGY

THE BUGS IN YOUR TEABAG COUNTED WITH EDNA

Yes, you are drinking arthropods in your tea.

Commercial tea leaves contain traces of arthropod DNA, according to a study in *Biology Letters*.

Aside from establishing that yes, there are insect traces in your teabag, the research demonstrates a nifty new technique: the ability to extract eDNA from dried plants.

Environmental DNA, or eDNA, refers to the DNA fragments left behind by many different species in a given environment.

It works best with samples of water. But a team of researchers based at Trier University and the Max Planck Institute for Evolutionary Biology, both in Germany, has figured out a method for getting eDNA from dried leaves.

The researchers extracted DNA from several dozen different commercially bought teabags and dried herbs, including chamomile, mint, tea and parsley.

They were able to spot over 1,000 different species of arthropod from the eDNA they found.

NASA, KSENIYA OVCHINNIKOVA / GETTY IMAGES

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HUH?

SCIENCE EXPLAINED

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FOCUS: COVID

01

Around two in 100,000 Australians get post-vaccine myocarditis and its severity is much lower than in unvaccinated cases.

02

Wind instruments produce aerosols in much the same concentration and size as when we are talking or breathing, despite how explosive or sharp the noises sound.

03

Studies show that long COVID is real and symptoms persist for longer than 12 weeks in 7.8–17% of cases.

04

A *Scientific Reports* study found birds living in and around developed areas in the north-western United States expanded their ranges into cities during COVID lockdowns.

05

In a survey of nearly 40,000 participants, 42% reported heavier periods following vaccination.

06

A *JAMA* study found 35% of health workers exposed to COVID-19 who were wearing a mix of surgical masks and N95 respirators were infected, compared to 21% for healthcare workers who wore N95s exclusively.

07

Research published in the *NZ Medical Journal* from the Institute of Environmental Science and Research found saliva tests had very similar detection rates to nasal swabs.

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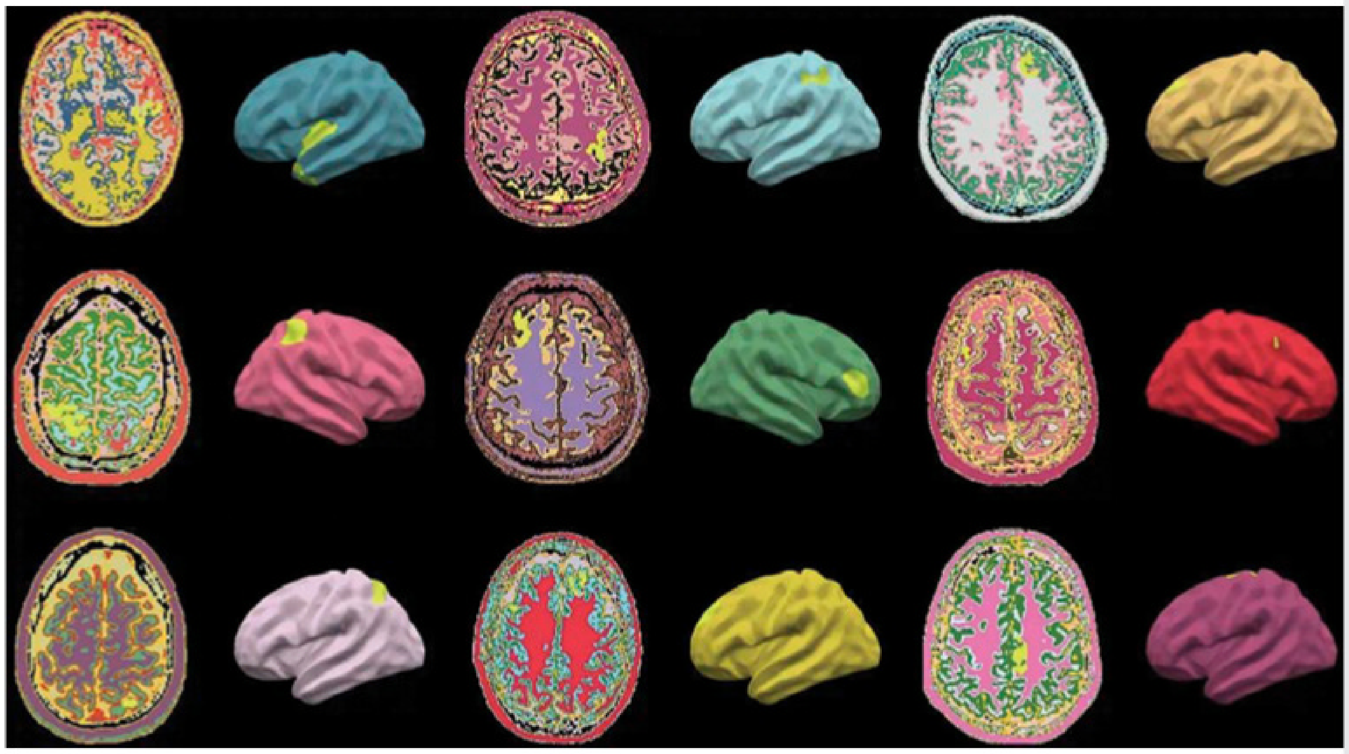
CREDIT: JESSE ORRICO, UNSPLASH

BIOLOGY

Could AI help predict epilepsy in children, leading to earlier treatment?

Epilepsy is thought to affect about 250,000 Australians.



▲ Brain abnormalities identified by the MELD AI algorithm (highlighted in lime green) on MRI scans of children and adults with epilepsy from around the world.

Machine learning has been used to create an algorithm that can diagnose epilepsy more consistently.

The algorithm automatically learns to detect lesions from thousands of MRI scans of patients and has been shown to reliably detect lesions, including many missed by radiologists.

Focal cortical dysplasia (FCD) are a leading cause of drug-resistant epilepsy. FCDs are typically treated with surgery, but identifying the abnormalities is a challenge. The Multi-centre Epilepsy Lesion Detection (MELD) project used more than 1,000 patient MRI scans from 22 global epilepsy centres to develop an algorithm to find FCDs. Researchers defined cortical features (details in the outer layer of the brain's cerebrum) from the MRI scans of 300,000 locations across the brain. They trained the AI to look at features like how thick or folded the cortex/brain surface was.

The team then exposed the algorithm to examples labelled by expert radiologists as being either healthy or having FCD. The algorithm detected FCDs in 67% of cases. Out of the cohort, 178 participants were considered by radiologists to not have FCD. Yet the MELD algorithm found the FCD in 63% of these cases.

LEFT: SAKCHAI VONGSASIRIPAT / GETTY IMAGES. RIGHT: UCL, JEFFREY HAMILTON / GETTY IMAGES

DISCOVERY

WHEN FOOD HAS A FACE, PEOPLE PREFER NOT TO EAT IT

"No, not the buttons! Not my gumdrop buttons!"

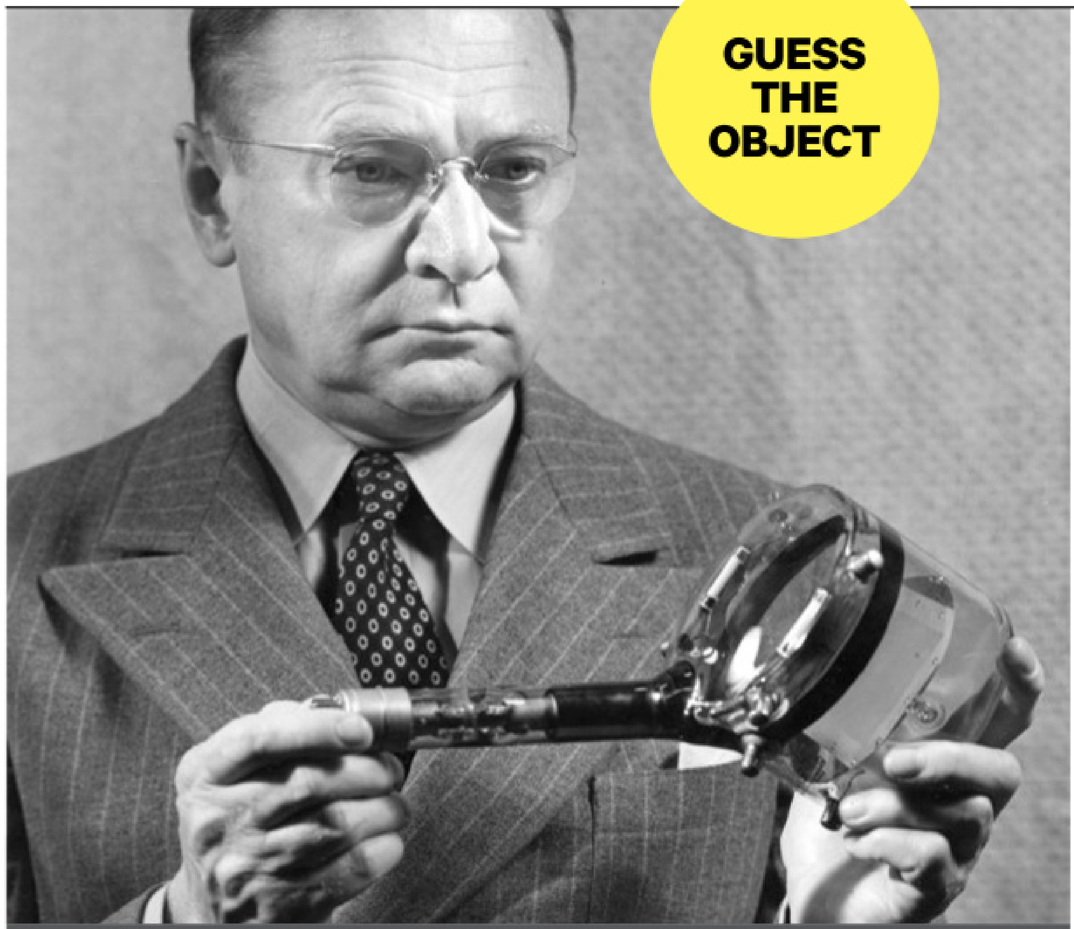
When food is given human-like features, people do not like to eat it, research from the University of Innsbruck, Austria, in the *Journal of Consumer Psychology* has found.

Anthropomorphism – attributing human characteristics – has long been a popular marketing strategy for food products (think talking M&M's, or the Australian company that puts smiley faces on pies).

The paper reports on studies testing people's responses. Three involved apple advertising. After seeing the ad featuring an apple with a face, consumers reported lower desire to eat an apple, and said they would enjoy eating an apple less. The exception was people who self-identified as being 'cold-hearted'.

In another test, participants were offered a choice between a gingerbread biscuit shaped like a man or a tree. People were more likely to buy the person-shaped biscuit, but when invited to eat one of the biscuits, most preferred to eat the tree shape.

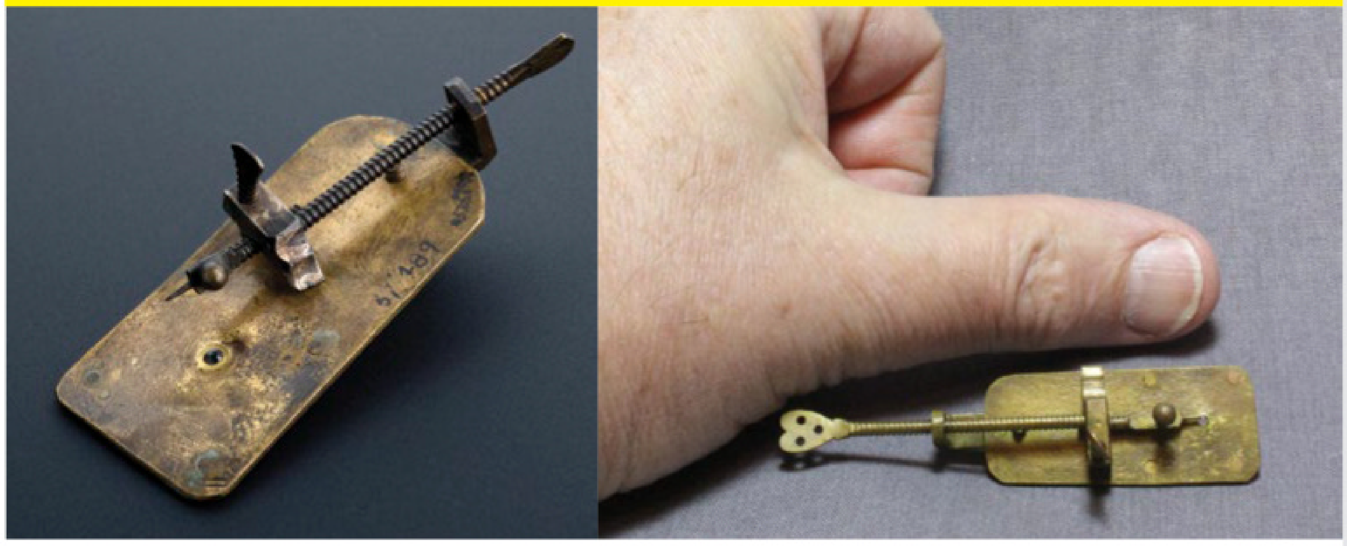
GUESS THE OBJECT



ICONIC INVENTION

Given the importance of the creations that flow from this object, we all *ought* to know what it is, and the name of the man that invented it (he's the serious-looking fellow in the suit). Nearly a century ago, he filed his first US patent application for a certain system; that application, and a follow-up two years later, described some of the principles of this gadget, which was finally made in the 1930s. The rest, as they say, is history. We know you can Google, but where's the fun in that? Tell us what you think it is. The correct answer – and/or the most creative – will be published in our next issue.

Send your hunches to contribute@cosmosmagazine.com



Last issue's object was far from mysterious for several readers. The first correct answer – from Dermot Allen – came with the ink barely dry on magazine pages: Dermot was spot-on in saying the item is "considered to be the world's first microscope, made by the Dutch scientist [Antonie van] Leeuwenhoek". Not surprisingly, van Leeuwenhoek (1632–1723) is known as the 'father of microbiology'. Other correct object pickers include Patrick Flynn, Tony Little and 18-year-old Kaemon Ah Kuoi-Simich. Our favourite guess came from 11-year-old Anna Kuznetsova: "I believe it is a thumb measurer used back in the olden days … to determine if [someone was] a witch or not." Well played, Anna – and please enter again.

MATHEMATICS

UKRAINIAN BECOMES THE SECOND FEMALE FIELDS MEDAL RECIPIENT

Maryna Viazovska is one of four to win the prestigious award.

Ukrainian mathematician Maryna Viazovska has become the second woman ever to win the Fields Medal, often referred to as the Nobel Prize for mathematics. Viazovska is one of four recipients of the medal, along with Hugo Duminil-Copin (from France), June Huh (US), and James Maynard (UK).

Viazovska, who currently works at the Swiss Federal Institute of Technology in Lausanne, was awarded the medal for, among other things, solving the sphere packing problem in eight dimensions.

"It was summer, it was rather stuffy on the train. On the train, I thought, since nothing seems to work, let me write the problem out one more time," said Viazovska.

"In school, they taught us that your head is full of rubbish until you write things down to put them in order. So, I am writing it out, and I get this functional equation. I look at it and I think: 'I should be able to solve it.' And, indeed, I solved it – it only took a couple of months."

BOTTOM: WIKIMEDIA COMMONS. TOP: RCA / OFFICE OF WAR INFORMATION / PHOTOQUEST / GETTY IMAGES

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PHYSICS

Curved-space robot defies known laws of physics

The discovery has implications for locomotion without propulsion.

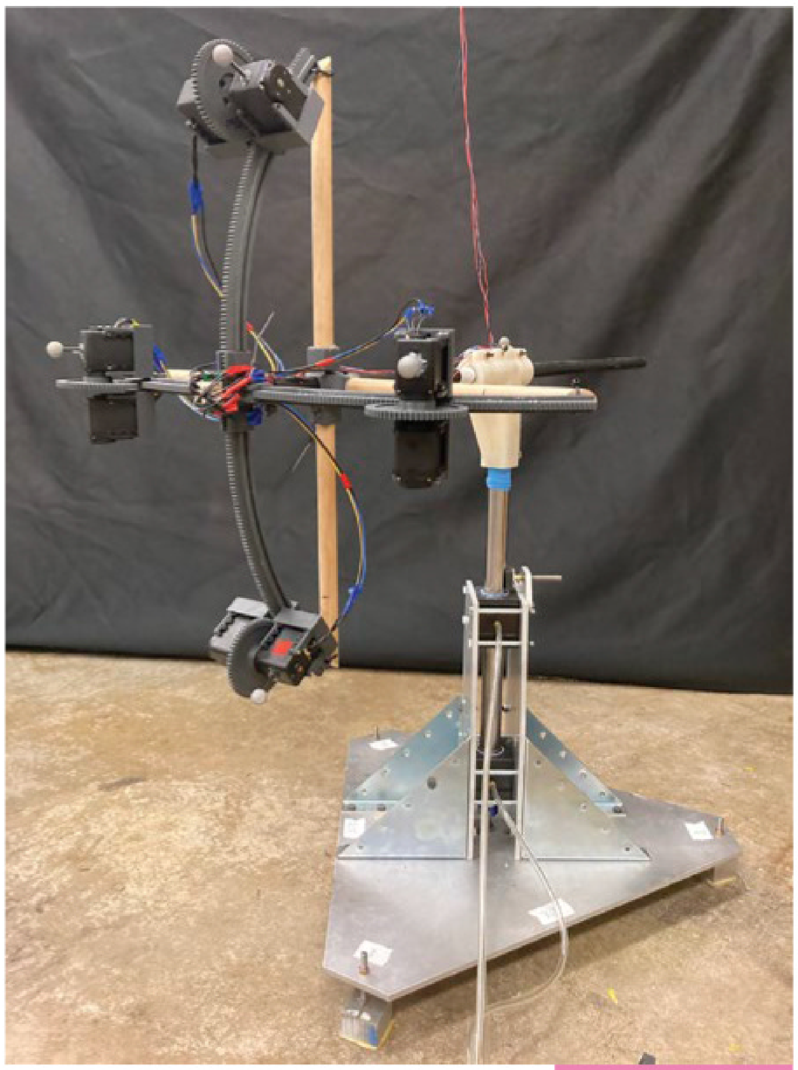
A robot engineered at Georgia Institute of Technology (Georgia Tech) has done the unthinkable and flouted a steadfast law of motion, suggesting that new laws need to be defined. Such new principles may have applications in new forms of locomotion without propellants.

Newton's third law states that for every action there is an equal and opposite reaction. So, when a human takes a step, we push against the Earth and the Earth pushes back, propelling us forward. But this only works thanks to friction. Without friction (or with minimal friction, for example, when there's a banana peel on the ground) there is no push – we just slide straight over the ground and can't move forward, instead falling back to Earth.

The same is true of locomotion. Rockets, for example, eject massive amounts of matter at high speed to push themselves in the opposite direction. Animals in the sea and air push against water and atmosphere respectively. There is always a push to move.

We generally think of space in terms of what are called Cartesian coordinates – the x-, y- and z-axes of three-dimensional coordinate space that we all used in high school. These axes all jut out from an 'origin point' at right angles to each other and continue ad infinitum in straight lines.

But space can be visualised as curved as well.



▲ Experimental realisation of a swimmer on a sphere with actuated motors on a freely rotating boom arm.

JOHN M LUND PHOTOGRAPHY INC / GETTY IMAGES, GEORGIA TECH.

In a study published in *PNAS*, a robot has bypassed the need for a thrust in order to change momentum by making use of curved space.

"We let our shape-changing object move on the simplest curved space, a sphere, to systematically study the motion in curved space," says lead researcher Zeb Rocklin, assistant professor in the School of Physics at Georgia Tech.

"We learned that the predicted effect, which was so counter-intuitive it was dismissed by some physicists, indeed occurred: as the robot changed its shape, it inched forward around the sphere in a way that could not be attributed to environmental interactions."

To make sure that the effects induced by the curvature of the robot's space dominated, the physicists had to isolate the system as much as possible from external forces.

The curved space was produced by placing a set of motors on curved tracks, attached to a rotating shaft to produce a spherical space.

Friction was curtailed using air bearings and bushings – low-heat and low-mess alternatives to ball bearings. Gravity was diminished by aligning the rotating shaft with Earth's gravity.

Although only slight, friction and gravity were seen to hybridise with the curvature of the space itself to produce a strange dynamic with properties that could not have been produced by either friction or gravity on their own. So, the team demonstrated not only how curved space can be realised, but also how it fundamentally challenges basic concepts attributed to the laws of flat space.

"This research also relates to the 'Impossible Engine' study," says Rocklin. "Its creator claimed that it could move forward without any propellant. That engine was indeed impossible, but because spacetime is very slightly curved, a device could actually move forward without any external forces or emitting a propellant – a novel discovery."

TECHNOLOGY

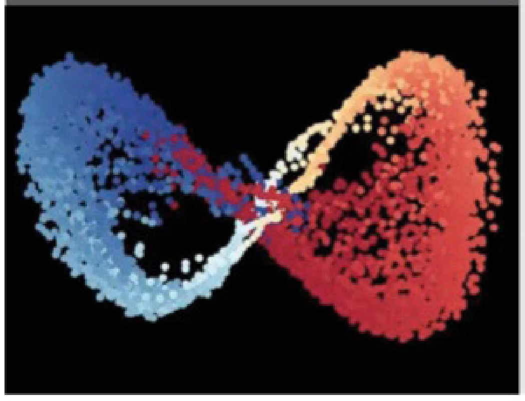
ARTIFICIAL INTELLIGENCE TOOL SWINGS INTO ACTION

Analysing pendulum videos, the AI identified variables not present in current mathematics.

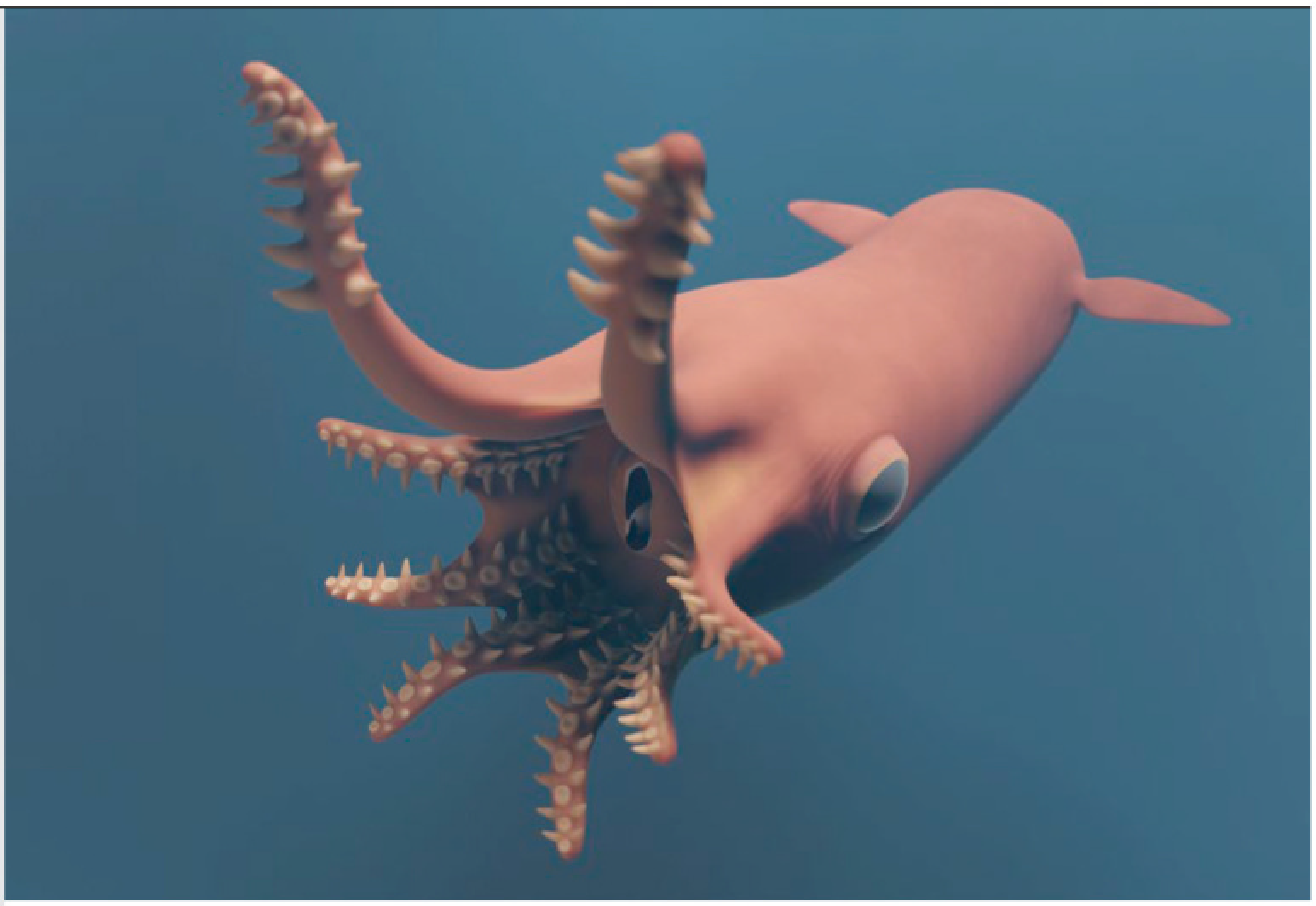
Roboticists at Columbia Engineering developed an AI program to review video data and search for the minimal set of variables that fully describe the observed physical dynamics of the swinging of a pendulum.

Double pendula can be described with four 'state variables': the angle and angular velocity of each of the two arms. After examining videos for a few hours, the AI identified 4.7 variables.

Researchers were able to correlate two of the variables to the angles of each pendulum's arm, but "we tried correlating the other variables with anything and everything we could think of: angular and linear velocities, kinetic and potential energy, and various combinations of known quantities," explains lead author Boyuan Chen. "But nothing seemed to match perfectly. We don't yet understand the mathematical language it is speaking."



BOYUAN CHEN/COLUMBIA ENGINEERING, A. LETHIERS, CR2P-SU.



BIOLOGY

The Jurassic world of the vampire squid

How these cephalopods survived across two mass extinction events.

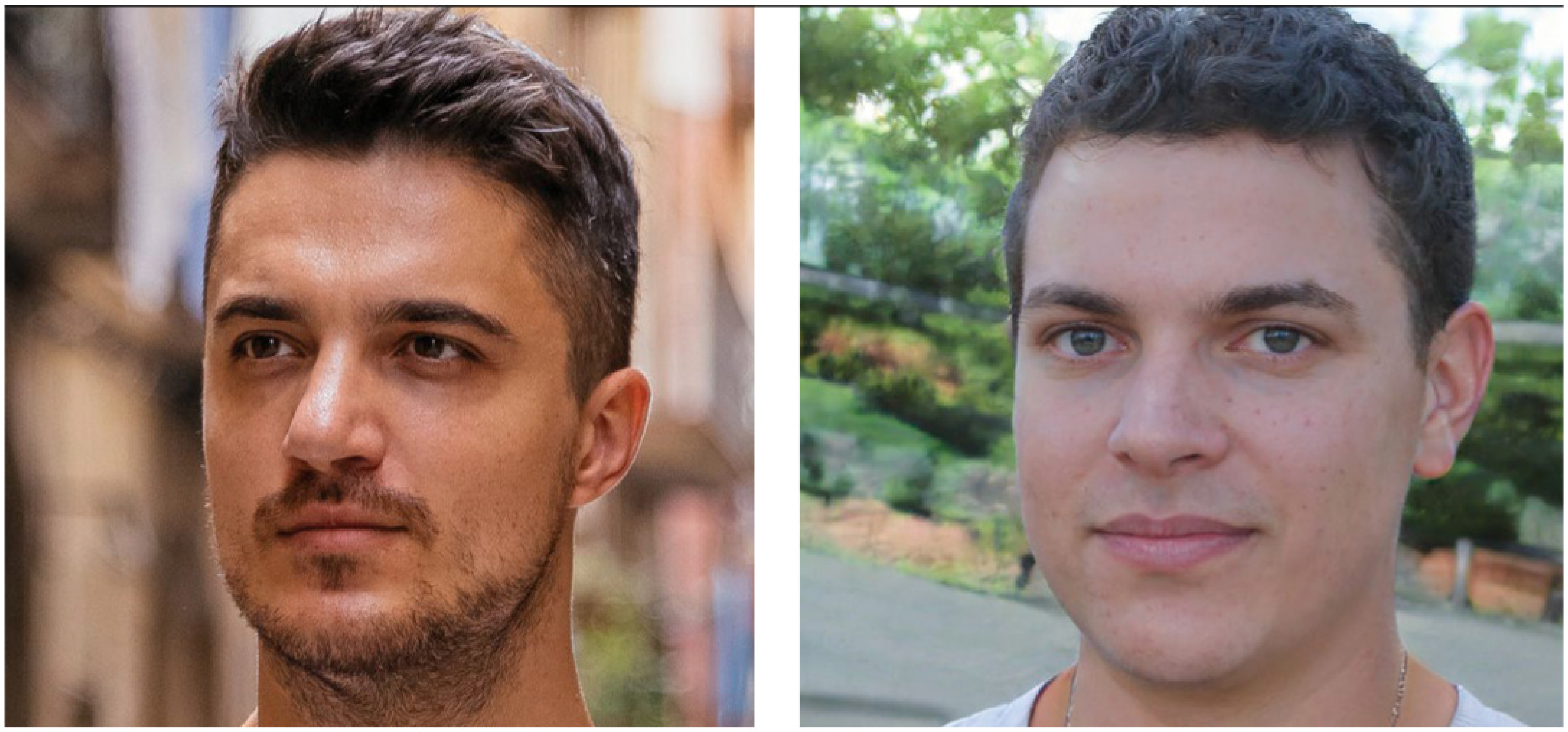
When you think *Jurassic Park*, you probably imagine a chomping T-Rex, or even a giant snapping Mosasaurus leaping out of the ocean. But how about vampire squid?

Though it didn't make the cut into any blockbuster movie, the vampire squid is one of the most mysterious creatures of the ocean, with a single species still alive to this day. The vampire squid *Vampyroteuthis infernalis* lives in extreme deep-ocean environments that often have little oxygen, feeding on detritus floating around the abyss.

Using modern 3D imaging techniques, exceptionally preserved fossil specimens of an ancient relative, *Vampyronassa rhodanica,* have been re-analysed. Unlike the modern-day species, this Jurassic vampire squid revealed it was well adapted to actively hunt, and had suckers that could hold on to its prey.

"Suckers are really useful for the identification of these animals at high taxonomic levels," says Dr Patrick Smith, one of Australia's fossil cephalopod experts. "This study gives us a much better resolution of how those suckers were constructed and how they compare to other living and extinct cephalopod groups."

V. rhodanica lived 164 million years ago, had eight arms and two small fins across their small oval-shaped body of around 10 centimetres in length. Muscular suckers on the tips of two long arms could create a watertight seal, aiding the manipulation and capture of its quarry. It also had conical appendages for sensing prey, indicating it was an active hunter.



Which one of these images is of a real person, and which is a deepfake?

LEFT: ALEXANDER SPATARI / GETTY IMAGES. RIGHT: THISPERSONDOESNOTEXIST.COM

TECHNOLOGY

Which of these is a deepfake? Your brain knows the answer before you do

The uncanny valley still exists in EEGs.

Deepfakes – AI-generated videos and pictures of people – are becoming increasingly realistic. This makes them the perfect weapon for disinformation and fraud.

But while you might consciously be tricked by a deepfake, new evidence suggests that your brain knows better, according to a paper in *Vision Research*.

While you can't consciously spot the fake (for those playing along, the face on the right is the phony), your neurons are more reliable.

"Your brain sees the difference between the two images. You just can't see it yet," says co-author Associate Professor Thomas Carlson, a researcher at the University of Sydney's School of Psychology.

Volunteers viewed a series of several hundred photos, some of which were real and some of which were fakes, generated by a GAN (Generative Adversarial Network, a common way of making deepfakes).

One group of 200 participants was asked to guess which images were real, and which were fake, by pressing a button. A different group of 22 participants didn't guess, but underwent electroencephalography (EEG) tests while they were viewing the images. The EEGs showed distinct signals when participants were viewing deepfakes, compared to real images.

"The brain is responding different than when it sees a real image," says Carlson.

"It's sort of difficult to figure out what exactly it's picking up on, because all you can really see is that it is different – that's something we'll have to do more research to figure out."

The EEG scans weren't foolproof: they could only spot deepfakes 54% of the time. But that's significantly better than the participants who were guessing consciously. People only found deepfakes 37% of the time.

"If we can learn how the brain spots deepfakes, we could use this information to create algorithms to flag potential deepfakes on digital platforms like Facebook and Twitter," says Carlson.

It could also be used to prevent fraud and theft.

"EEG-enabled helmets could have been helpful in preventing recent bank heist and corporate fraud cases in Dubai and the UK, where scammers used cloned voice technology to steal tens of millions of dollars," says Carlson.

"In these cases, finance personnel thought they heard the voice of a trusted client or associate and were duped into transferring funds."

But it's no guarantee. The researchers point out that, even as they worked, GANs got more advanced and generated better fake images than the ones they used in their study.

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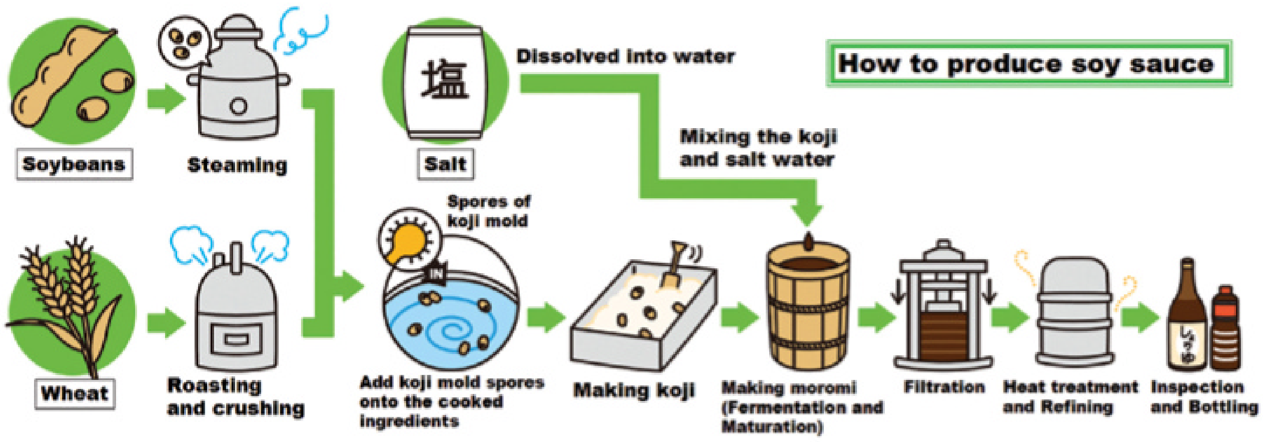
CHEMISTRY

Food scientists find 50 flavour compounds in soy sauce

The simple salty sauce is surprisingly complex.



Soy sauce is not only one of the world's oldest condiments, it's also one of the most popular – at least eight million tonnes is consumed globally each year. But what gives soy sauce its complex salty, umami flavour that makes it so delicious?

Soy sauce originated in China more than 2,500 years ago, and is made by fermenting a combination of salt, enzymes and mashed soybeans. However, decoding the flavours of this food is particularly challenging because of the complex processes involved in its creation, including the microbial breakdown of compounds over time.

Now, in a study in the *Journal of Agricultural and Food Chemistry*, a team has identified 34 key tastants – chemicals that produce a taste sensation by activating taste receptor cells (TRCs) and taste-related pathways of the nervous system.

They then combined these compounds to try to recreate the taste of soy sauce. But a panel of 27 assessors found that this recreation didn't taste quite right. The team hypothesised that small proteins could be missing from its batch, and used a sensoproteomics approach to identify 14 umami, kokumi and salt-enhancing peptides present in concentrations of 166–939 micromoles per litre .

The addition of these to their sauce of now over 50 flavour compounds produced a condiment with comparable complexity, taste intensities and 'mouthfulness' to the real deal. Some of the salt-enhancing proteins gave a salty sensation, which had only previously been brought on by table salt and other minerals. These salt-flavoured peptides could potentially serve as a seasoning alternative to table salt that could be better for your heart.

ANTHROPOLOGY

SLOW AND STEADY WINS THE BRAIN GAME

Small genetic changes separate modern humans from ancestral brain development.

Our closest relatives are Neanderthals (split from modern humans at least 500,000 years ago) and their Asian relatives the Denisovans (split from modern humans around 800,000 years ago). The differences between *Homo sapiens* and these other groups are encoded in changes in amino acids, about 100 of which differ in modern humans.

Published in *Science Advances*, research from the Max Planck Institute for Evolutionary Anthropology investigated how six of these amino acids impact brain development, introducing them into mice. The six amino acid positions are identical in mice and Neanderthals.

"We found that three modern human amino acids ... cause a longer metaphase, a phase where chromosomes are prepared for cell division," says lead author, Felipe Mora-Bermúdez. "This results in fewer errors when the chromosomes are distributed to the daughter cells of the neural stem cells, just like in modern humans."

MIYAJIMA SOY CO., ARTIST: JOHN GURCHE. PHOTOGRAPHER: CHIP CLARK. VIA WIKIMEDIA

EARTH

Chaos is more common in ecology than we thought

Insects are particularly chaotic – who knew?

Nature is full of chaos. A new study has confirmed it and found that chaos is more common in ecosystems than previously thought.

Populations of living things change a lot in nature. Figuring out patterns in these population changes requires some fairly difficult maths.

In general, ecologists sort these fluctuations into three broad categories: ‘regular’ (fluctuating around a stable equilibrium), ‘random’ (impossible to predict) – or ‘chaotic’ (predictable in the short term but not the long term, and sensitive to very small changes).

“Knowing whether these fluctuations are regular, chaotic or random has major implications for how well, and how far into the future, we can predict population sizes and how they will respond to management interventions,” says Dr Tanya Rogers, an ecologist at NOAA Fisheries, US, and lead author on a paper describing the research, published in *Nature Ecology & Evolution*.

Older research typically found that chaos was rare in ecological populations.

“There’s a lot more data now, and how long a time series you have makes a big difference for detecting chaotic dynamics,” says co-author Stephan Munch, a NOAA Fisheries ecologist and adjunct professor at the University of California, Santa Cruz, US.

“We also showed that methodological assumptions made in prior meta-analyses were biased against detecting chaos.”

The researchers used newer algorithms to examine 172 datasets from the Global Population Dynamics Database.

They found evidence of chaos in more than 30% of the populations they assessed.

Plankton and insects were the most chaotic, while birds and mammals were the least and fish were in the middle.

“A lot of short-lived species tend to have chaotic population dynamics, and these are also species that tend to have boom-and-bust dynamics,” says Rogers.

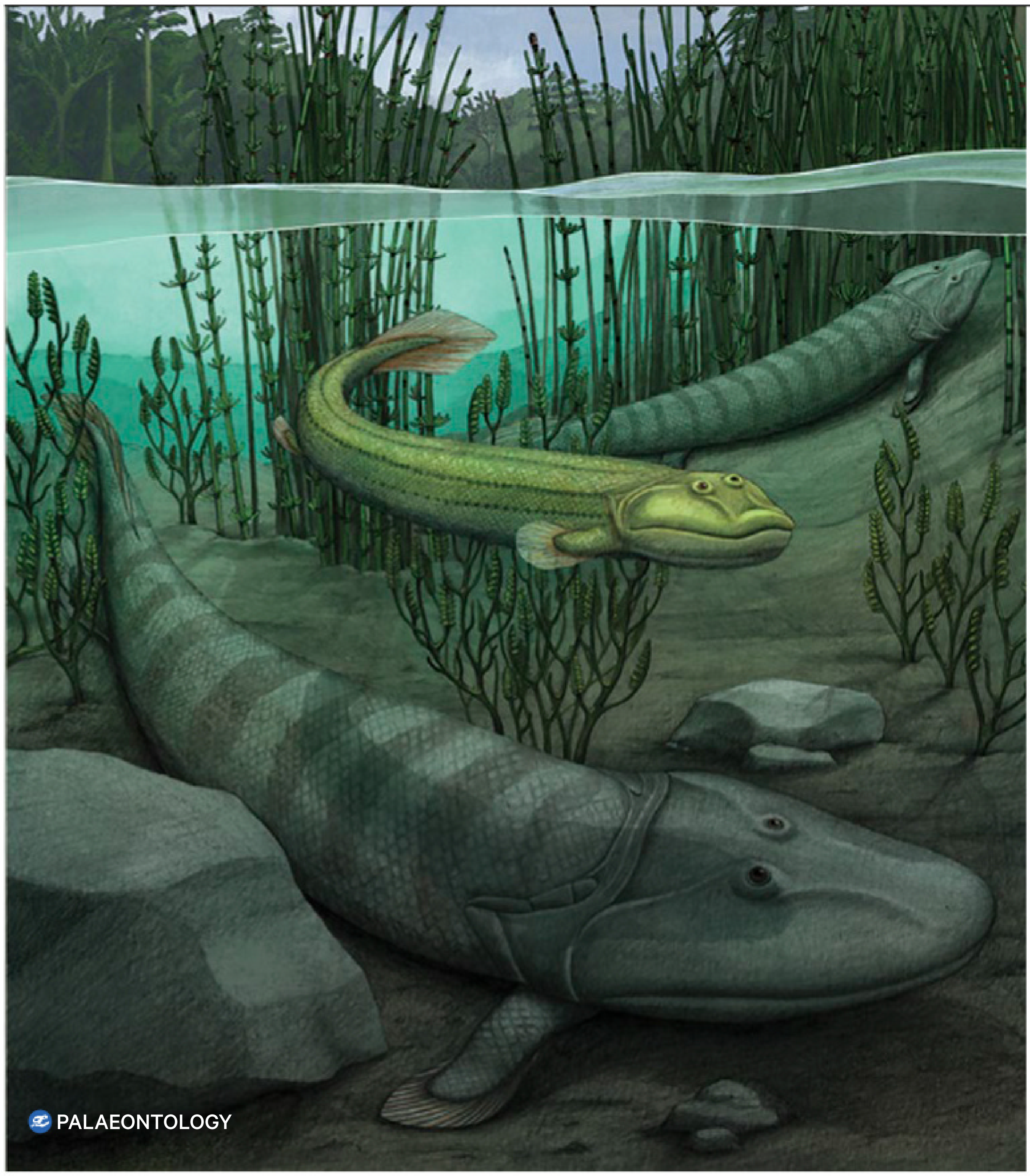
The researchers warn against assuming regular population dynamics when making ecological predictions – especially among short-lived species.

“From the fisheries management perspective, we want to predict fish populations so we can set limits for fishery harvests,” says Rogers.

“If we don’t recognise the existence of chaos, we could be losing out on short-term forecasting possibilities using methods appropriate for chaotic systems, while being overconfident about our ability to make long-term predictions.”

> **“If we don’t recognise the existence of chaos, we could be losing out on short-term forecasting possibilities...”**

JOHN M LUND PHOTOGRAPHY INC / GETTY IMAGES



▲ Illustration of *Qikiqtania wakei*, centre, in the water with its larger cousin, *Tiktaalik roseae*.

ALEX BOERSMA

While our ancestors went to land, this fishapod went back into the water

Fossils of a 400-million-year-old fishapod show it began the transition but was more adapted to water life.

As with all land-based life on Earth, our ancient ancestors evolved in our planet's primordial seas before taking first steps onto land. For vertebrates like us, the animal associated with this evolutionary stride is the 375-million-year-old *Tiktaalik roseae*.

For its leap of faith into the Darwinian bible, Tiktaalik has received some tongue-in-cheek flak from internet memesters who blame the amphibious trailblazer for all of life's modern problems.

Now, research in *Nature* shows a new fossil appears to have joined Tiktaalik on land – before deciding to return to the sea, sparing its ancestors the pain of 21st century life.

Qikiqtania wakei would have been just a little over a metre in length – small compared to Tiktaalik, which could grow to nearly three metres. Though the species are similar, Qikiqtania's body is more suited to life in water. Among the fossils are partial upper and lower jaws, portions of the neck and scales, and, importantly, a complete pectoral fin including a humerus bone lacking the muscle ridges that would indicate a limb built for walking on land.

Qikiqtania's upper arm was smooth and curved, suggesting it spent its life paddling underwater. The unique arm bones imply that it returned to the water after its ancestors began to use their appendages for walking.

Qikiqtania's fossils were found just days before Tiktaalik was discovered, but they were placed in storage and largely forgotten for 15 years. It was only in 2020 that a CT scan of one of the rocks revealed a pectoral fin.

"We were trying to collect as much CT data of the material as we could before the lockdown, and the very last piece we scanned was a large, unassuming block with only a few flecks of scales visible from the surface," explains co-author Justin Lemberg. "We could hardly believe it when the first grainy images of a pectoral fin came into view … That was in March 2020, and the university shut down all non-essential operations the following week.

"This was by no means a fascinating block at first, but we realised during the COVID lockdown when we couldn't get in the lab that the original scan wasn't good enough and we needed to trim the block. And when we did, look at what happened … It's a fabulous story."

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On the surface

Nanoscale paints that collect freshwater from the air. Hull surfaces that allow ships to move more efficiently through the ocean … You need a scanning electron microscope to see these "next big things", writes Chiara Neto.

Natural water extraction in action: the Namib Desert's *Physosterna cribripes* beetle boasts hydrophilic bumps on its back to pluck fog droplets from the air. The trick becomes doing it at scale.

FROM FAR LEFT: COURTESY OF CHIARA NETO; TRACY ROBB / WIKIMEDIA

There's a natural example of a surface engineered to facilitate the extraction of water from the atmosphere. It's a beetle (*Physosterna cribripes*) that lives in the Namib Desert in Africa. It exposes hydrophilic (water-loving) bumps on its back to the prevailing winds at dawn, when the fog comes in. These structures capture free-form fog droplets in the air. The rest of its back is hydrophobic, so the droplets roll off easily and reach the beetle's mouth. This way it can survive in an environment that has no ground water.

Around the world there's been interest in replicating this idea. I've been working on freshwater capture for about 11 years now. The idea is to use the power of surfaces to achieve an advanced function – and there is no objective more important than to extract water for use by people, animals and plants.

But we've recently moved away from that particular beetle example, because it turns out you can get very little volume out of that structure. In the last three years or so, we've moved on to a new project that we call ACWA: advanced capture of water from the atmosphere.

Within one cubic metre of air at 70% humidity and 30°C, there is approximately one tablespoon of water. If the humidity is higher, there is obviously more water. The idea is to extract this water from the atmosphere and use it where we need it, when we need it.

We've designed surfaces that, when exposed to the sky, actually become cooler than the environment around them. By being cooler, they condense the water that is in vapour form. The idea is similar to what happens when you get a bottle of milk out of the fridge – droplets form on the outside of the bottle because water in the air condenses on the coldness of the surface. Obviously, the volume of water that condenses is proportional to the area of the surface, so if we want to do this on a large scale, we need to capture water over large surface areas – without having to use any energy, so it is sustainable and affordable.

The concept is called daytime radiative cooling. Basically, you're trying to design materials that have particular optical properties so they reflect solar light, and don't heat up under the Sun. And secondly, they emit heat at a particular wavelength called the atmospheric window, so heat is not reabsorbed near the surface, and therefore it spontaneously cools.

We've designed nanoporous polymer surfaces that, due to their structure and composition, can be cooler than the air

THOMAS VOGEL / GETTY IMAGES

> **Our best collection rates are so far in the order of 350ml of water per square metre of surface per day, but we're developing the materials to improve this.**

around them. So if the humidity is high – in the order of 70% or above – you can reach the conditions of dewpoint (the point at which vapour changes to liquid). If you then design the surface so the droplets readily roll off, you can collect them, giving access to a small but precious amount of water that can supplement other existing supplies. It's the same type of water quality that you would get from rain.

We've been running prototypes installed on the roof of one of the buildings here at the University of Sydney. Our best collection rates are so far in the order of 350 millilitres of water per square metre of surface per day, but we're developing the materials to improve this.

The surface doesn't look anything special – just like plain white paint. This is because the structure is at nanoscale, within the bulk of the film. You need a scanning electron microscope to see the structure.

We are close to commercialisation. The idea is that it will be applied like paint to the roofs of buildings, warehouses or farm buildings, where a small but predictable supply of water throughout the year can make the difference between survival and failure. It could be used to feed water to high-value plants, or to support animals that need a constant amount of water. There are any number of applications.

In its final form, it will be a standard paint formulation. So it's not particularly energy intensive to make, and uses very common chemicals that are already in the market.

We're also working on functional lubricant-infused surfaces that are designed to be slippery, so they don't allow any liquids or solids to attach to them. With this feature we can do two things that are really important for sustainability of flow processes.

Firstly, we can prevent the attachment of bacteria and larger organisms. This is especially relevant in the marine environment, where you get fouling from the attachment of algae, barnacles and larger organisms that occurs whenever a boat or any sort of underwater infrastructure is exposed to the sea. Basically, we have a liquid-like coating that doesn't allow anything to stick to it. It won't actually kill the species, it just doesn't allow them to hook onto the surface. You can also prevent fouling by species such as proteins or cells onto biomedical devices.

There's very, very promising data showing that it works. Importantly, in the marine application, it uses non-toxic liquids: we use silicone oil, which is not something that you want bucketloads of in the ocean, but it's not toxic to marine life. And the volume that is shown as necessary for this effect is actually minute – of the order of 0.2 millimetres of the oil per square metre of surface.

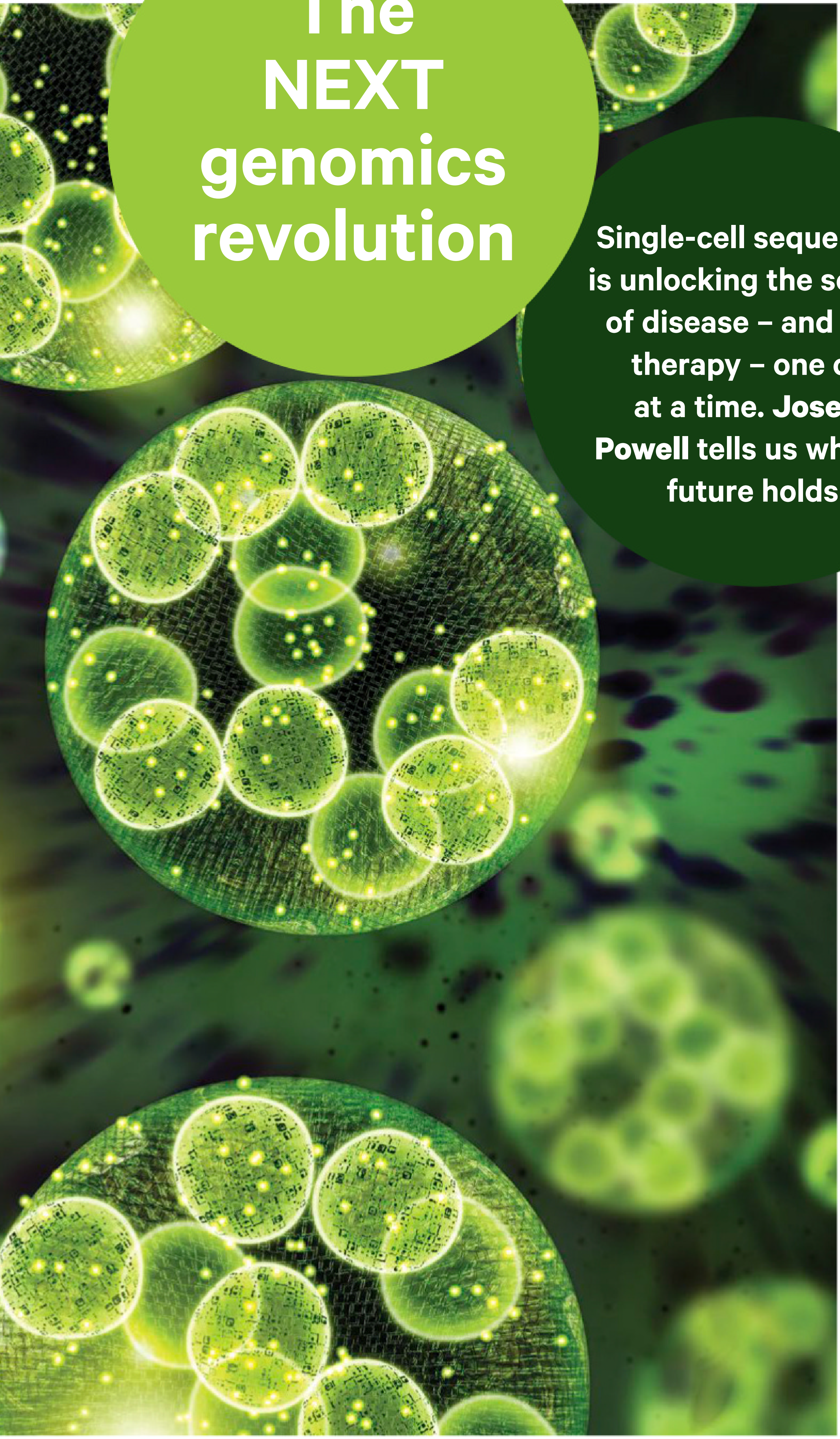
The second application of lubricant-infused surfaces is in drag reduction. Any object moving through water requires energy to drive it because there's frictional drag that is resistance to flow. If you can allow the water to slip on the surface, reducing the frictional resistance, then you need less energy to drive that object. We've shown on a microfluidic scale that we can reduce drag by close to 20% relative to a flat surface. We are in collaboration with a small enterprise, MicroTau, based in Sydney, to fabricate these structures on a larger scale. It might open the scope for application on ship hulls.

Chemistry is a subject I have always been comfortable with. Both my parents are chemists – my Dad was a university professor, and my Mum was a high school chemistry teacher. It is a natural fit for me. I was preparing to choose my Honours project at the University of Florence in Italy when a professor there purchased a new type of instrument called an atomic force microscope. I became fascinated by the idea that you could image surfaces at the nanoscale, and that's when my interest in patterns and structure on surfaces started. It's very exciting where that interest is leading. ◉

CHIARA NETO is a professor of physical chemistry at the University of Sydney and Australian Research Council Future Fellow. Her research considers functional nanostructures and the design of new materials for sustainable technologies.

The NEXT genomics revolution

Single-cell sequencing is unlocking the secrets of disease – and drug therapy – one cell at a time. Joseph Powell tells us what its future holds.



EZUME IMAGES / SHUTTERSTOCK

The mapping of the human genome in 2003 was a genuinely important milestone in human history. But a second major revolution that started in 2009 is ongoing, and really picked up in 2016: the ability to generate genomic data on individual cells, at scale. It means we are now able to resolve how things work at the biological unit of the body.

You can call this revolution single-cell sequencing. It's basically a set of technologies able to generate genomic data at the level of one cell, and do that for very large numbers of cells in parallel. This is important because almost every biological process in multicellular organisms, like humans, starts at the level of an individual cell.

If you think about what any cell is, it's a functional part of the body. It might be a cardiac muscle cell. It might be a neuron in your brain. It might be a rod or cone cell in the retina, turning light into vision. And they all have very specific functions. But even if you look at cardiac muscle cells, for example, you realise that how they're working can be quite different. We call this heterogeneity – variation between the cells.

Diseases arise when something is wrong in a particular subset of cells. By studying the resolution biology at this level, you can start inferring which cells are going wrong and contributing to disease, or alternatively, which cells are doing something that might be targetable by a particular therapy, therefore improving drug efficacy.

This type of precision medicine will revolutionise drug treatment procedures. Cancer is probably the easiest example to translate. Here's something that starts literally at the point of an individual cell with a sort of somatic mutation; it does something it shouldn't do, doesn't die, starts proliferating, dividing, dividing, dividing, and as cells divide, you get new mutations within that cancer. You end up with a single cancer tumour that can have a series of clonal cell types, each with different genetic profiles.

The strategy at the moment is to assume they're all the same, typically use a single treatment, and blast them. This can be really effective at killing perhaps 90% of the cells, or maybe more, but there might be a set of cells that have a particular genomic profile that is completely treatment resistant. Then you might have a recurrence a few months or years later – and that's a common story you see in cancers. There's some form of effective remission, but it comes back, and the reason is that we don't target the individual diversity or make-up of cells and the clones of a particular patient.

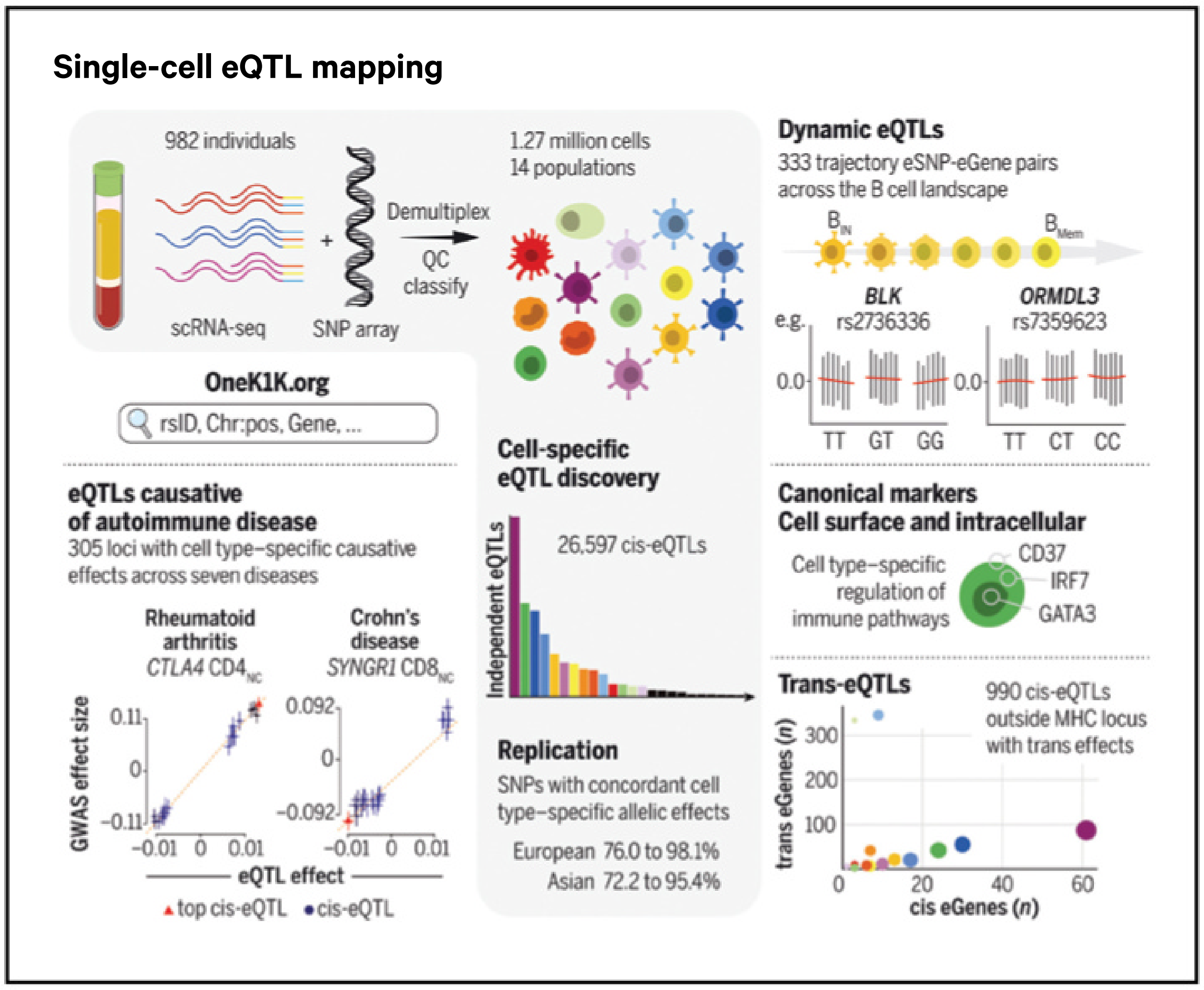
This is the nut that is cracked with single-cell sequencing: you can clearly identify those cloner cells. And if there are therapies that can be used at what we call multi-line therapy, using multiple drugs or treatment options for the same patient, then we have an informed way to do that.

What often happens is we'll find particular cells we don't know an effective treatment for, but once we've got their profile we can start figuring out how we can target this new cell type. This is a really active area of research for us, using this single-cell genetic information to rapidly inform new therapeutic development.

You generate vast amounts of data. You're sequencing hundreds of thousands of genomic pieces of information on one cell, and you do that for tens of thousands to millions of cells. This is where there's a strong intellectual contribution, a combination of thinking very deeply about the way genetic differences act between different people, and then using that intersection of mathematics and biology to identify the signals that you get from that sort of data.

Growing up in a rural part of the UK, I was always drawn to the natural world. I specialised in sciences at school and went to university to study zoology. My interest was field science, but during my undergrad I was exposed to evolutionary theory and how maths can be used to integrate theories about evolution in the natural world. By the end of my Masters, I was drawn to understanding how the genome works and how it applies to disease.

A strong motivator in my PhD and subsequent work has been combining a natural curiosity for figuring things out with making a difference. With the maths I specialised in, I had the option to stay as a postdoc or go into finance when I finished my PhD. The salary differential was enormous, but my dad made a short argument: at the end of your life, will you feel you made more of a difference by working in finance or science?


Single-cell eQTL mapping

SCIENCE, VOL 376, ISSUE 6589

> It's going to be impactful to have this ability to move the whole field of medicine across many disciplines and usher in the new era of genomic medicine.

In my world, we call the maths we use statistics, but I guess machine learning is most accurate. It lends itself to genetics because humans have enormous genetic diversity. It's bases of DNA, bases of code, that you boil down using maths to identify which particular parts are doing something important, or something they shouldn't, like causing disease.

We've already taken important steps across COVID, cancer, and neurological and neurodegenerative disorders. Within 10 years we'll be able to use cellular genomics to dramatically increase drug discovery and quality of drug decision-making processes.

It's going to be impactful to have this ability to move the whole field of medicine across many disciplines and usher in the new era of genomic medicine.

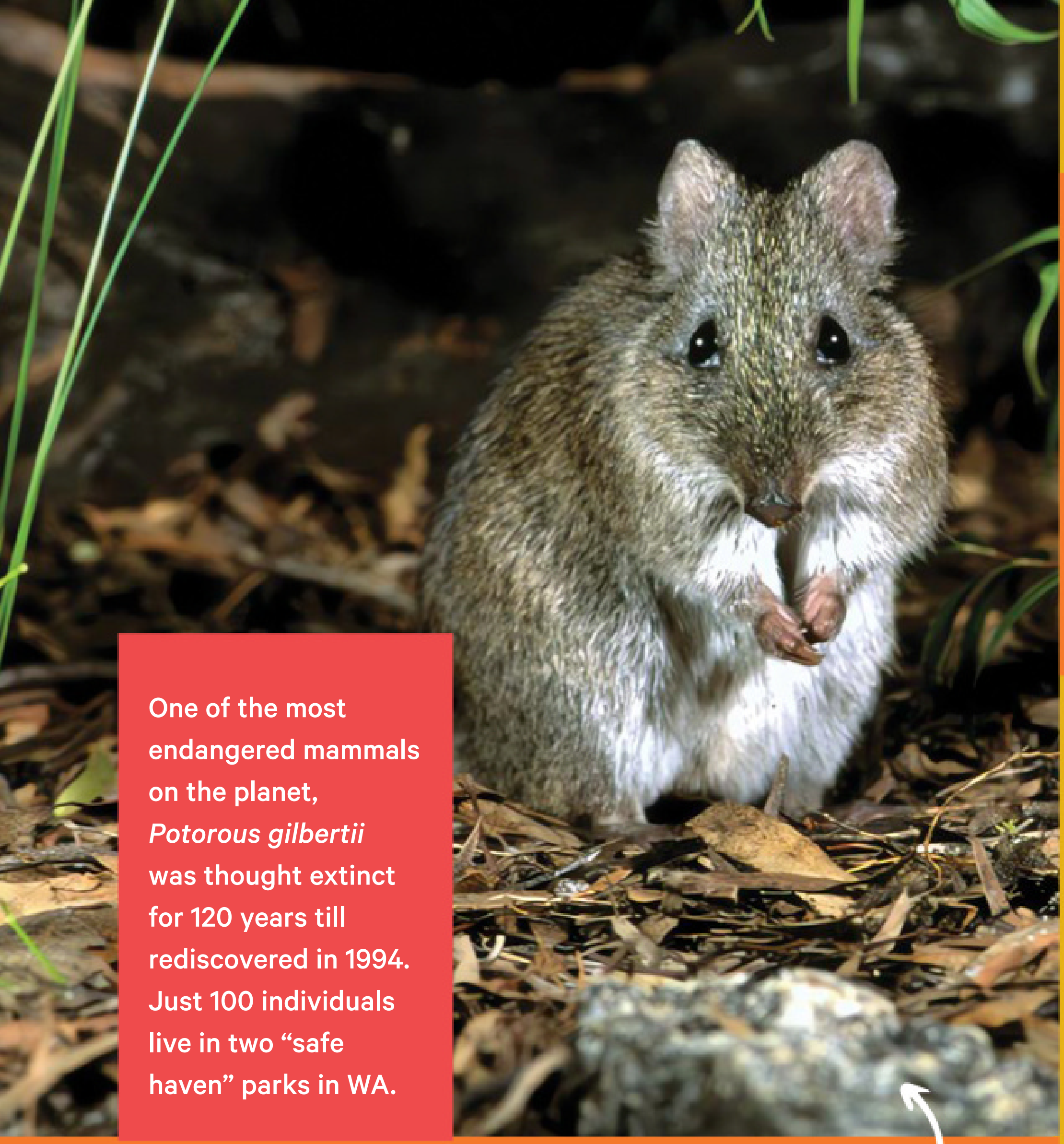
It's a privilege to work as a physicist. We do what we find most interesting and are paid to conjure up hypotheses that sound like science fiction. I can't ask for a more fulfilling career. ◉

PROFESSOR JOSEPH POWELL is Director of Cellular Science at the Garvan Institute of Medical Research, and Deputy Director of the UNSW Cellular Genomics Futures Institute.

Theory of natural election

Over recent months *Cosmos* took nominations from around the world, before running a poll to crown Australia's inaugural Mammal of the Year. It's a fun celebration of our special species, but in a year when six mammals have had their conservation status threat level increased, as **EUAN RITCHIE** writes, it's also a chance to reflect on how much we have to lose …

CLOCKWISE FROM TOP LEFT: DICK WALKER, GODDARD PHOTOGRAPHY, JJ HARRISON

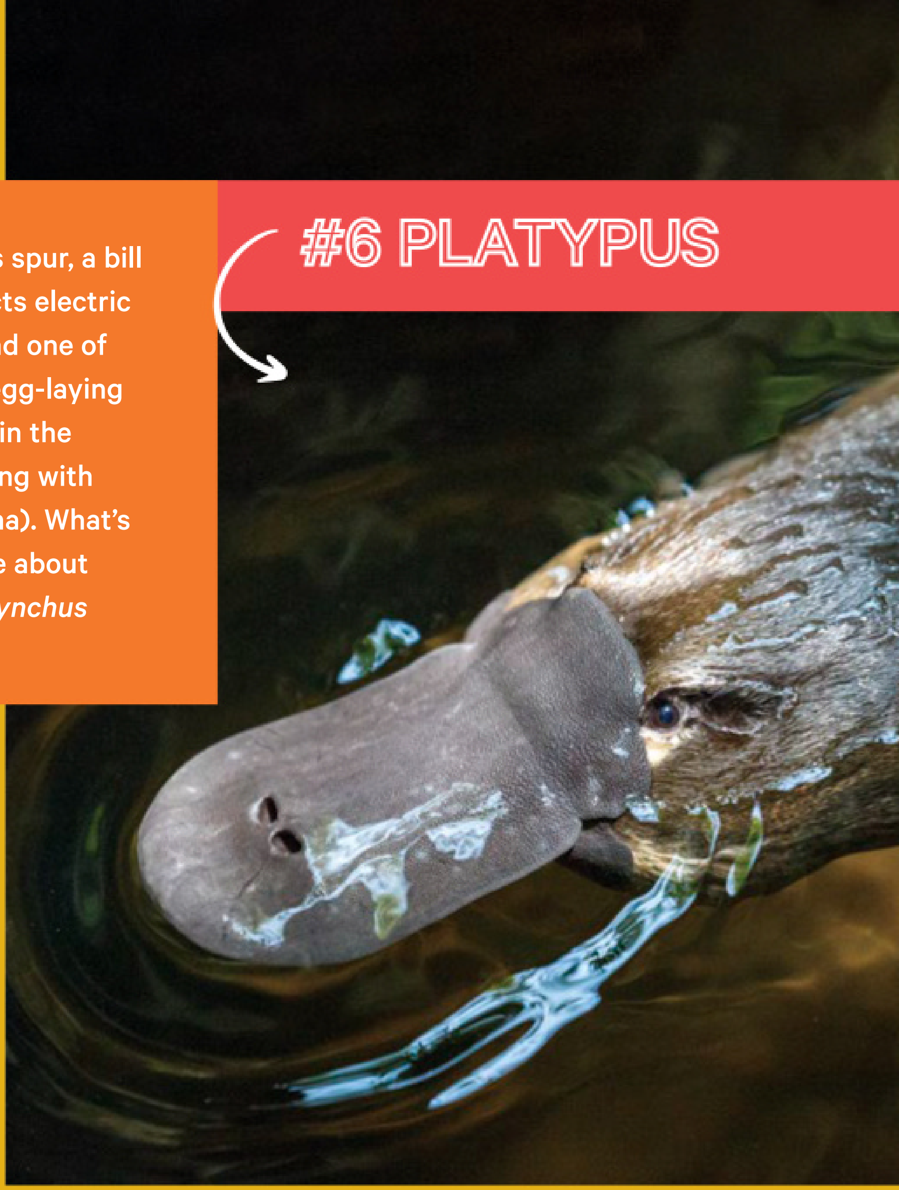


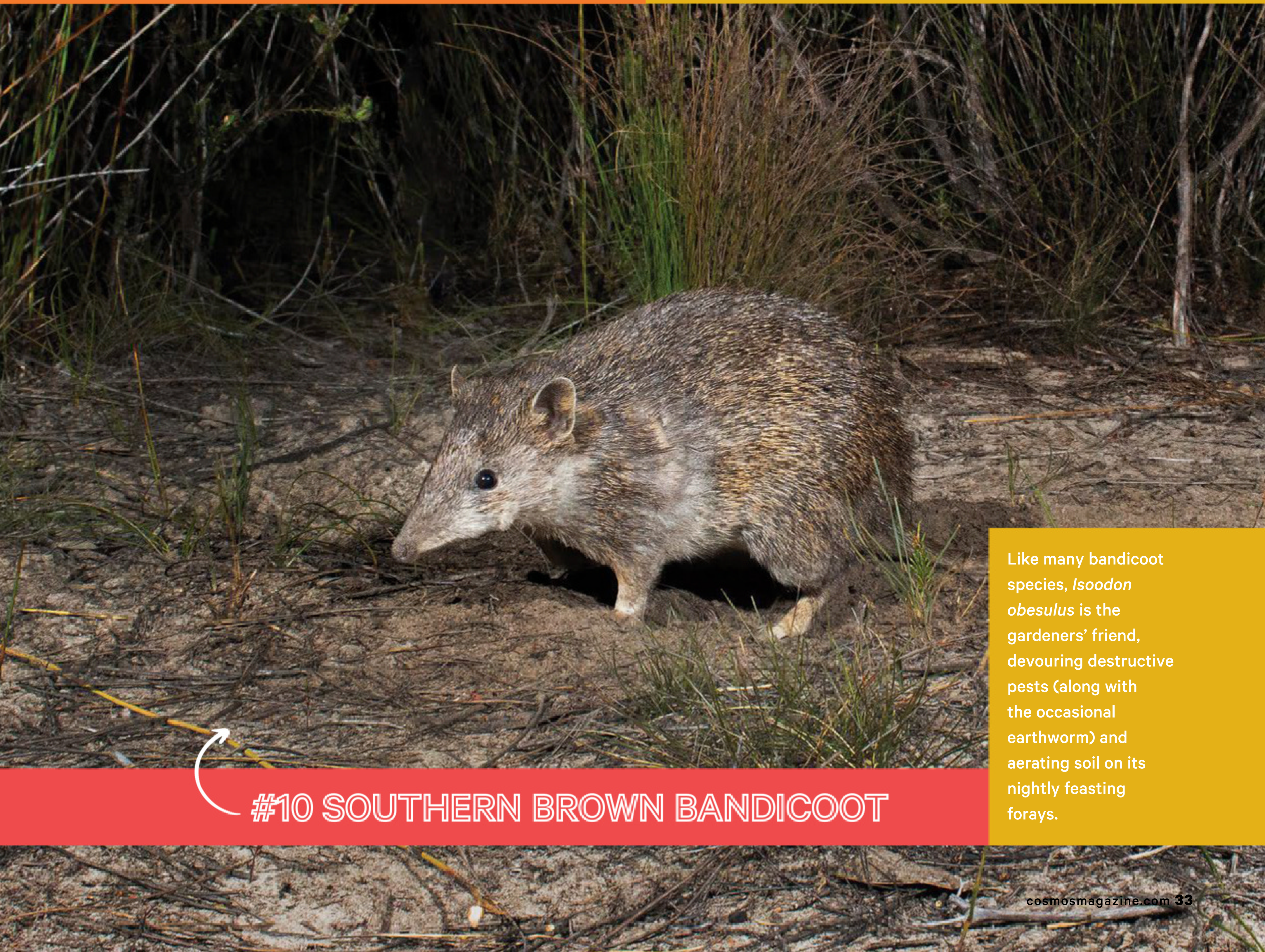
One of the most endangered mammals on the planet, *Potorous gilbertii* was thought extinct for 120 years till rediscovered in 1994. Just 100 individuals live in two “safe haven” parks in WA.

#5 GILBERT’S POTOROO

#6 PLATYPUS

Venomous spur, a bill that detects electric current and one of only two egg-laying mammals in the world (along with the echidna). What’s not to love about *Ornithorhynchus anatinus*?





#10 SOUTHERN BROWN BANDICOOT

Like many bandicoot species, *Isoodon obesulus* is the gardeners’ friend, devouring destructive pests (along with the occasional earthworm) and aerating soil on its nightly feasting forays.

Super strong and delightfully dapper, *Dasyurus hallucatus* made David Attenborough's list of 10 species he'd put on his personal ark. The marsupial's range has shrunk from the top one-third of the continent to isolated pockets.

#9 NORTHERN QUOLL

A tiny, critically endangered bat, weighing less than a Tim Tam biscuit, has won the inaugural Australian Mammal of the Year contest. The fact that prior to this competition, very, very few Australians had ever heard of the southern bent-wing bat is a large reason why such a contest was so important, and was also a resounding success. It was never just about the winner, but much, much more. Without the love and tireless work of a group of dedicated people, the southern bent-wing bat could so easily be yet another tragic statistic in Australia's long and growing list of species extinctions since European colonisation.

More than 100 species have been driven to extinction in the last ~230 years, at least 39 of which are mammals, and more broadly, over 1900 species and ecological communities are under threat. The pace of decline is swift and alarming for some: during this year's competition, the recently and newly described southern and central greater gliders moved from vulnerable to an endangered conservation listing.

Australia's iconic mammals are recognised the world over, but dig deeper and it's clear that many of the more than 350 native species that inhabit this continent's lands, skies, and waters – more than 85% of which are found nowhere else on Earth – remain widely unknown to most people, apart from just a handful of names. But very few are committed to memory, and for most we have only a rudimentary sense of their behaviour, ecology and what factors affect their day-to-day lives.

I'm enamoured with Australia's mammals. As a mammalogist, I've had the immense privilege to work in rainforests, deserts, savannas, alpine areas, and forests across this country for close to 30 years. In that time I've learnt some of the secrets of our fabulous fuzzballs, and strive with many other passionate people to provide greater care and conservation of these remarkable species. But in all honesty, I often think we don't comprehend just how lucky we are.

The joyous cacophony of a grey-headed flying-fox camp and the beauty of their silhouettes against an apricot sky as they fly out across Melbourne's suburbs each night in search of food. The silky, graceful movements of rakali as they swim along creeks, rivers or around jetties, industriously foraging on yabbies, freshwater mussels and other shellfish. The seemingly incongruous sight of tree kangaroos that bound and crash about in rainforest tree-tops, not on the ground, where their close relatives such as red and grey kangaroos are more well-known. The sheer awe of watching a feathertail, yellow-bellied, savanna or other glider, leap and effortlessly glide between trees. Bandicoots feverishly digging holes in urban lawns, to the annoyance of some, but the joy of others who know how this digging improves soil condition and the health of vegetation communities. Australian fur

ABOVE: HENRY COOK / GETTY IMAGES. BELOW: ZOOS VICTORIA

#3 MOUNTAIN PYGMY POSSUM

Restricted to only three small locations in the Australian Alps, *Burramys parvus* hibernate under snow for 5–7 months of the year. Known only from the fossil record until its rediscovery in 1966. It's estimated that fewer than 2000 individuals remain.

#2 DINGO

Canis dingo has been part of Australia's cultural history for at least 4,000 years. It's a polarising animal due to its broad and voracious appetite; research also shows its importance as an apex predator controlling feral and overabundant species.

seals playfully swimming around excited snorkellers in Port Phillip Bay. And of course there are those that are more familiar: the quokka, common wombat, short-beaked echidna, humpback whale, platypus, numbat, greater bilby, koala, Tasmanian devil, and other icons. We are so very fortunate.

Amid the fervour, gamesmanship and humour of the competition, some important observations surfaced, and discussions were ignited. Perhaps the most interesting was people lamenting that three of the final four species in the competition were eutherian, or placental, mammals. These were the rakali, southern bent-wing-bat, and dingo, alongside the sole marsupial, the endangered mountain pygmy possum. But why should this be perceived as a bad outcome? Yes, it's true Australia is unquestionably the land of greatest marsupial diversity, and also home to two species of monotreme, but why not celebrate our eutherian mammals too? There are more than 90 bat and 60 rodent species, and over 50 species of marine mammals (seals and sea lions, dolphins and whales, and the inimitable dugong) in Australia. A more inclusive and encompassing view of our mammal fauna seems sorely warranted.

Another, often overlooked dimension of our mammals pertains to culture. Itjaritjari, kariri, koorrawal, kultarr, marti, ngilkat, numbat, pingki-tawutawu, pookila, quenda, tooarrana, wali, wilkurr, and wopilkara. These are just a handful of the many Indigenous names for native Australian mammals. How many do you recognise? As a non-Indigenous person it is not my place to speak about the deep cultural associations and knowledge First Nations peoples have of native mammals, but it was encouraging to see a greater awareness of this emerging during the competition, and I hope for more in coming years.

The dingo, the second-place winner, sparked controversy and passionate debate. As a long-time dingo researcher this was nothing new to me, but I know it was for many who followed the competition and were learning more about the dingo along the way. There were calls of 'dingoes aren't native', 'dingoes are barely Australian', and 'dingoes aren't a species'. Such protestations, and others, are why I have been so fascinated by the dingo for so long. I cannot think of a mammal that's more maligned and misunderstood.

The dingo forces us to confront challenging questions, such as just what does constitute being native? Must a species have evolved in Australia? Or if not, post-arrival, how long is long enough to be considered native? We don't know exactly how long dingoes have been in Australia, but we think they arrived, with or without help, somewhere between 4,000 and 10,000 years ago.

And as for what constitutes a species, it may come as a surprise to many, but science and scientists are a long way from reaching agreement on such a fundamental issue. Regardless of how dingoes may be perceived and categorised, I think it was wonderful that the very definition of an underdog made it so far in this inaugural competition. Dingoes force

#8 EASTERN BARRED BANDICOOT

Perameles gunnii is a conservation success story: only 150 remained in 1989, when a captive breeding program began. In 2013 it was declared extinct in the wild, but in 2021 was reintroduced to seven locations and its status upgraded to endangered.

ABOVE: ANGUS EMMET. BELOW: ZOOS VICTORIA

While many might think of marine mammals as international citizens, our northern coastal waters support most of the world's *Dugong dugon* population. The species is more closely related to elephants than other marine mammals.

#7 DUGONG

us to confront the tragedy and ongoing impacts of colonialism, and as uncomfortable as this may be, it's essential for progress in wildlife management and conservation, and of course on other social, cultural, economic and environmental fronts too.

If you were to poll 100 Australians about what they consider to be the world's most endangered mammals, tigers, elephants, giant pandas, rhinoceros, and possibly pangolins would feature heavily. How many would mention Australia's most critically endangered marsupial, Gilbert's potoroo? There are thought to be only 100–120 individuals left (for comparison it's estimated there are more than 1800 giant pandas remaining in the wild – although when it comes to extinction risk, it should never be a competition). Like the southern bent-wing bat, the survival of Gilbert's potoroo, a Lazarus species that was once already thought extinct, rests largely with the dedicated work of a small team of scientists and volunteers. Like many of our digging mammals (such as the rufous bettong and southern brown bandicoot), Gilbert's potoroo has a fondness for subterranean fungi, including truffles, and their excavations and spreading of fungal spores help to maintain intricate, essential relationships between plants, fungi and soil, and contribute to healthier ecosystems.

That Gilbert's potoroo reached the final five in Australian Mammal of the Year is remarkable. That it still struggles for adequate conservation funding is also, in my view, a source of great shame.

Despite the extraordinary mammal species that reside in Australia, and indeed more broadly our biodiversity in general – Australia has an estimated 21,119 plant, 349 freshwater fish, 740 bird (non-vagrant), 247 amphibian and 1065 reptile species – we are simply not providing sufficient care and protection, despite having the expertise and resources to do so. The majority of Australia's species are endemic, a consequence of this continent's long history of isolation and millions of years of evolution. Furthermore, on account of Australia's large size and hence diverse climate, ecosystems and habitat types, many species are also regionally restricted, for example, the honey possum in southwest Western Australia, Leadbeater's possum in Victoria or the northern bettong in North Queensland. Other species that now have relatively small and often fractured distributions, such as the numbat, greater bilby and chudditch (western quoll), once spanned large areas of mainland Australia.

#4 RAKALI

One of only two freshwater aquatic Australian mammals, *Hydromys chrysogaster* is a true "Aussie battler": widespread across town and country in waterways and coastal estuaries. Adults teach young how to open mussels, and lessons vary across different populations.

FROM TOP: SUNPHOL SORAKUL, JOSHUA PRIETO / GETTY IMAGES

#1 SOUTHERN BENT-WING BAT

Weighing about the same as a 50c coin and with a body length of 5cm, this marvellous microbat species has a restricted range along the coast across the borderline of South Australia and Victoria. Southern bent-wings migrate each spring to their breeding grounds: maternity caves in which hundreds of pups cluster in creches, raising the temperature of the caves by up to 12°C. Only three of these maternity caves are known to exist, so a temperature or weather event at any would be catastrophic – just one of the reasons why this charming, snub-nosed flyer is critically endangered. In breeding season it's estimated the southern bent-wing bat can eat about 25% of its 15g body weight in insects per meal and may eat 2–3 meals per night. In winter, the bats go into hibernation, roosting in the coolest sections of their chosen caves. Their body temperature drops as low as 2°C, which limits the loss of body fat.

An educational resource for this story is available at **www.education.riaus.org.au**

STEVE BOURNE / WIKIPEDIA

The majority of Australia's species are endemic, a consequence of our long isolation.

There seems often to be debate about one species' care taking money from another conservation effort, but this perpetuates the myth of a zero-sum game and a false dichotomy: it's not a question of access to sufficient funds – after all, there are tens of billions for submarines – it's a question of values, priorities, and politics. It's been estimated we spend about a 10th of what the US does on its endangered species recovery program, and roughly 15% of what is required to prevent extinction and aid species recovery. While far from sufficient, by comparison US spending on threatened species, which is mandated under law, is significant and has unquestionably aided the recovery of numerous species.

Australia is falling short. Importantly, it is also far cheaper and more effective to prevent species from getting into trouble in the first place than sending in the ambulances once they're critically endangered and at imminent risk of extinction. This requires treating the underlying causes of species decline and extinction, not just tending to the wounds and symptoms.

We cannot escape from the fact that if we want to continue enjoying and benefitting from our remarkable wildlife – the envy of people the world over – we must have stronger environmental laws that are enforced, and tackle key threats including land clearing, urbanisation, invasive species, disease, pollution and climate change. We must learn to better share spaces with wildlife. The good news is this is eminently possible in both our cities and in rural and regional areas, and much exciting work is already underway to work out how best to achieve this. And as this competition has highlighted, much more can be done to promote understanding of our wildlife.

Before I finish, I have a bone to pick. Common spotted cuscus, itjaritjari (southern marsupial mole), wangarru (yellow-footed rock wallaby), eastern pebble-mound mouse, djintamoonga (black-footed tree-rat), boongary (Lumholtz's tree kangaroo)... none of these top-shelf mammals made the final top 10! Good people, we all make mistakes, but such terrible oversights and travesties must not be repeated in the next round of Australian Mammal of the Year!

In all seriousness, thank you to all who helped make this inaugural competition the great success that it was, and it's my great hope that it'll help to forge much greater awareness and bring about far greater protection of arguably the world's most remarkable and extraordinary mammalogical assemblage. Here's to Australia's fabulous fuzzballs!

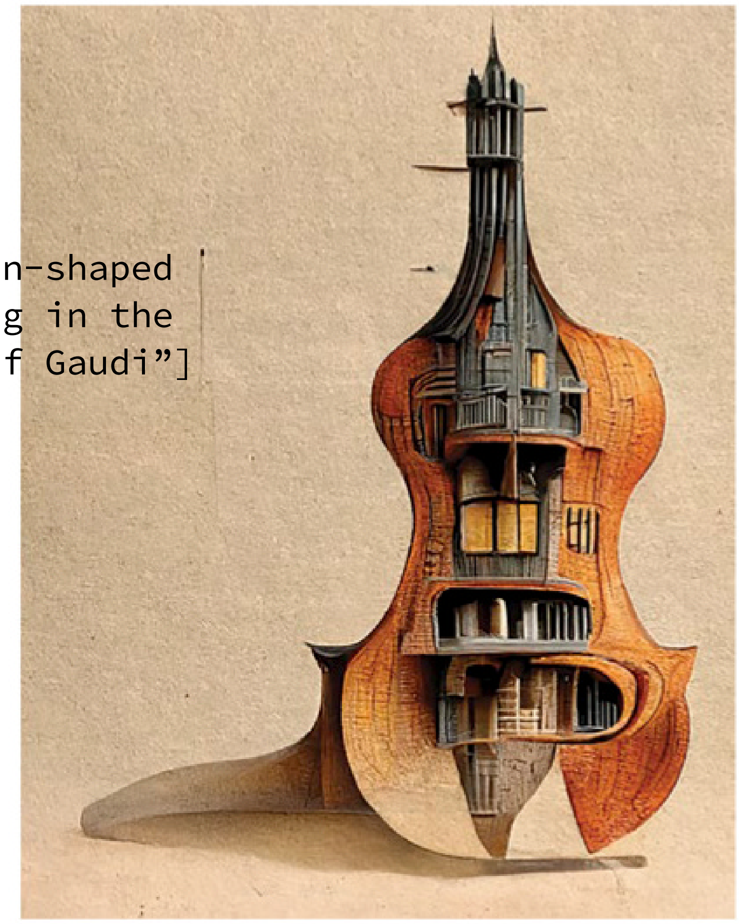
EUAN RITCHIE is a professor of Wildlife Ecology and Conservation at Deakin University. This is his first story for the magazine.

[“retro colour scheme sideways beautiful elegant 2d profile of face made of overlapping flowing magazine paper cut shapes with bird and nautilus”]

MIDJOURNEY X2

[A.I. Art]

As the tech develops, “AI art” is creating headlines around the world. But, asks **EVRIM YAZGIN**, how “creative” can AI really be?



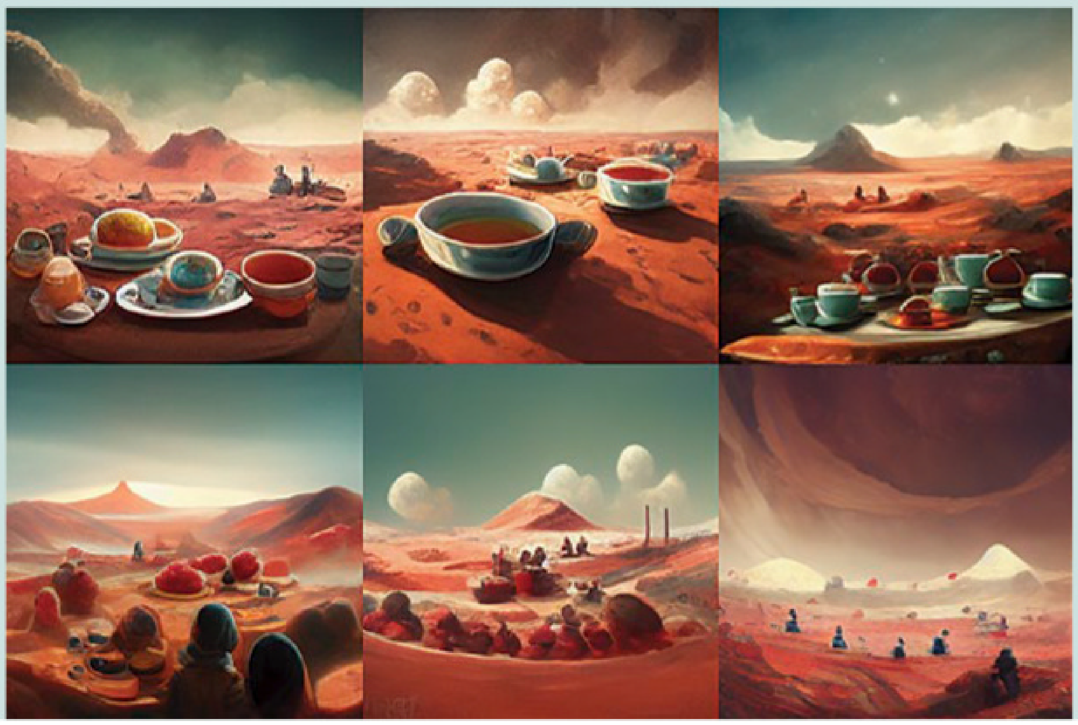
[“violin-shaped building in the style of Gaudi”]

Artificial intelligence (AI) tools are taking the world by storm, seemingly making their way into every facet of life. AI, or machine learning, software is already being developed for a plethora of applications in science and engineering, including self-driving cars, traffic control, ecosystem monitoring, climate modelling and in medicine.

But another area of artificial intelligence research has been making waves internationally, particularly on social media, in recent months.

Emerging out of the buzz around AI-generated art has been a lot of discussion – and confusion – around whether or not the AI is “creative”, what this means for human artists, and copyright (who owns the image? Who made it?) and potential dangers (like biased output or AI-generated misinformation).

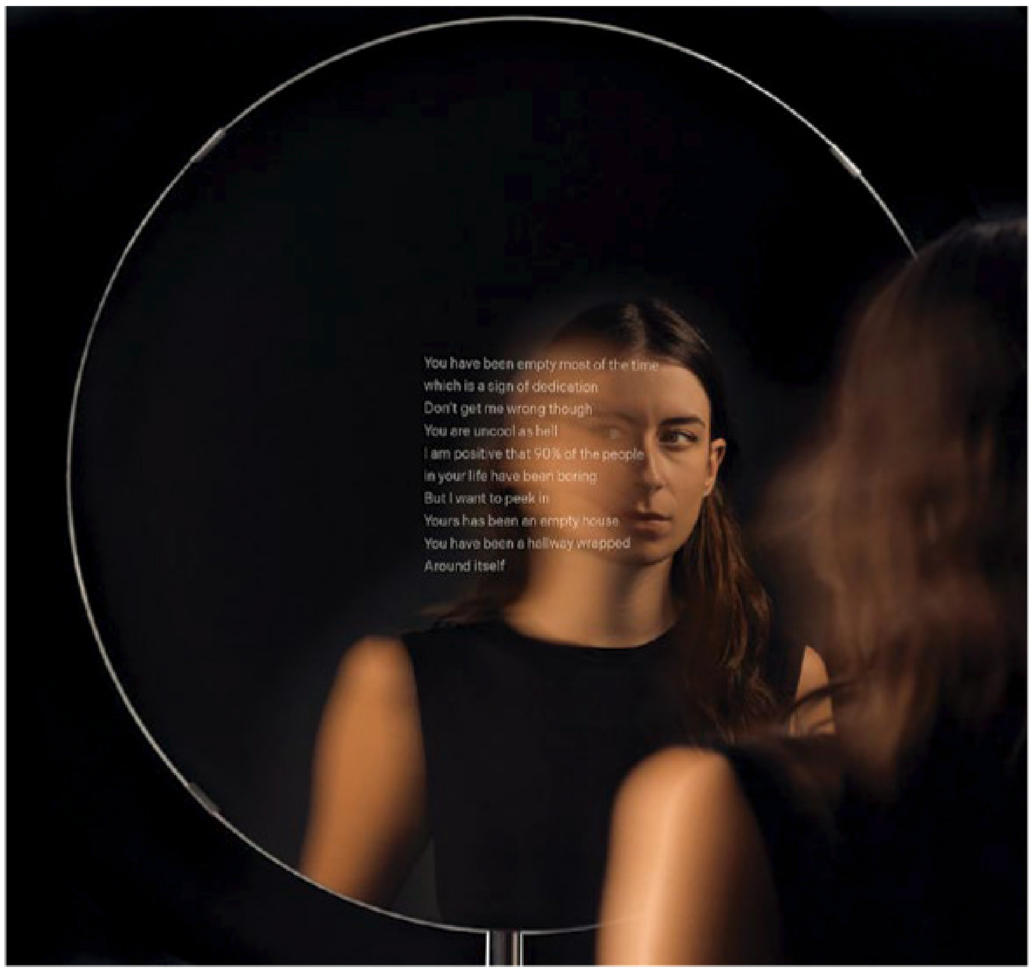
AI art has been around for decades, but exploded onto the scene with OpenAI’s DALL-E, an



[“tea party
on Mars”]

[“house keys
by Kandinsky”]

[“sunflowers,
photorealistic, 4k”]



You have been empty most of the time
which is a sign of dedication
Don't get me wrong though
You are uncool as hell
I am positive that 90% of the people
in your life have been boring
But I want to peek in
Yours has been an empty house
You have been a hallway wrapped
Around itself

At Sensilab researchers work with AI to create art like this mirror, which analyses a face and produces a poem based on the emotion it sees.

“intelligence augmentation” tool that scours billions of parameters to create images based on any text prompt you can think of. I would wager that a great many of us have already spent hours playing with the less powerful DALL-E mini, now called Craiyon.

Analysing billions of bits worth of data, Craiyon relates the user-submitted text to images it finds to produce drawings. Craiyon is fun, but its artistic talent is patchy: sometimes questionable, sometimes impressive.

Craiyon is almost endearing. My predominant thought while using the tool is “I see what you were going for there. Nice try.”

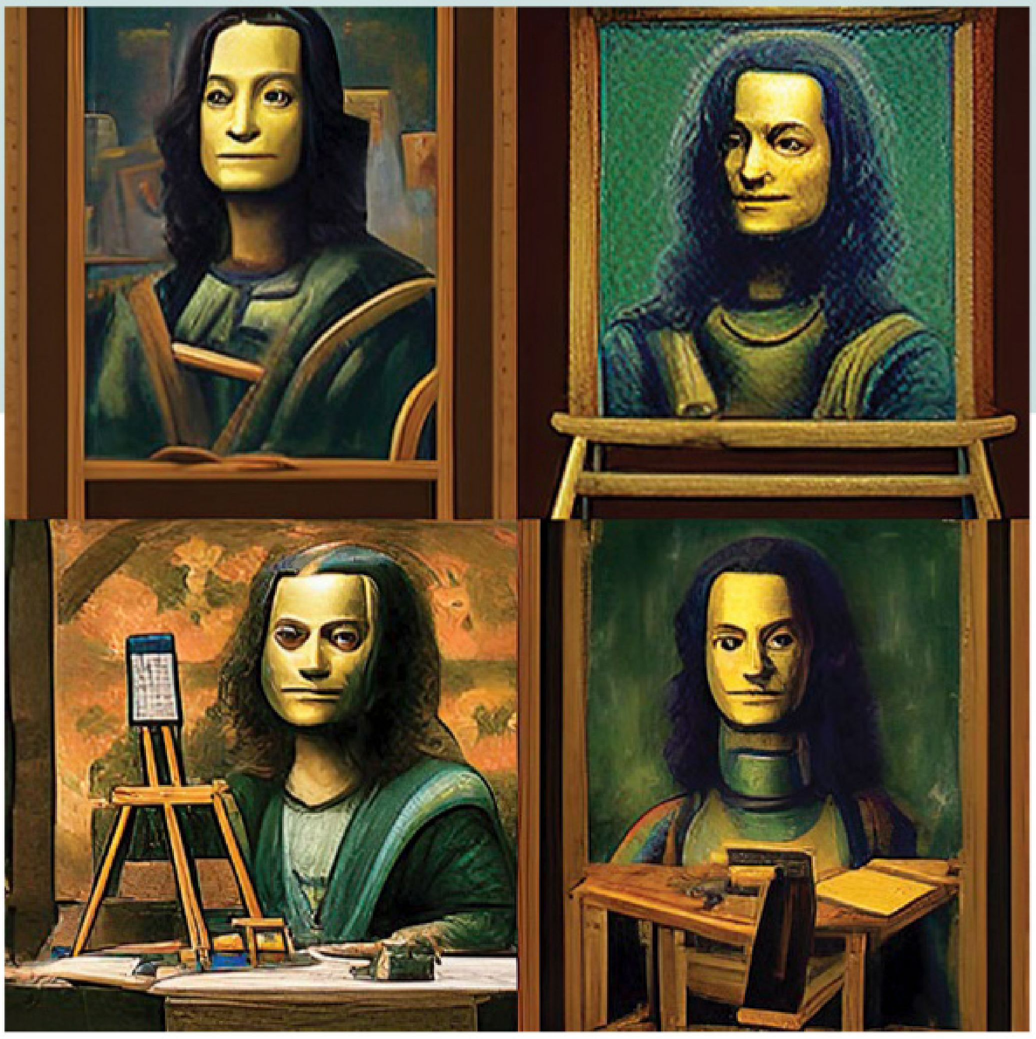
If Craiyon is the bumbling, lovable goofball, then Midjourney is its more sophisticated publicly available cousin. Midjourney has been in development for years. On 18 July, the company announced that Midjourney beta would be available, allowing people to generate up to 25 images. For more images, payment’s required. Since then a variety of increasingly complex features have come online.

The tool has sparked debate and questions about the role and intricacies of AI-generated art. It’s clear, for example, what the algorithm is going for with a straightforward descriptive prompt like “tea party on Mars”, as seen above.

BOTOM LEFT: SENSILAB. ALL OTHERS: MIDJOURNEY

[“ultra realistic watercolour painting of fullbody elvis wearing denim spacesuit”]

[“Leonardo da Vinci as a robot, sitting in front of an easel, working on a half-finished painting of the Mona Lisa”]



You can also give direction on the detail and style of the photo. For the sunflowers on the opposite page, I asked Midjourney to render them “photorealistic” and “4K”. You be the judge of how successful that was. And will someone please explain to me the eyeball in the bottom-right image of the set?

Some personal highlights. One of my favourite artists is Russian painter Wassily Kandinsky. How does Midjourney think Kandinsky would have portrayed house keys?

Midjourney also allows you to iterate on images you like, and “upscale” those you wish to see in more detail. On the previous spread there’s an upscaled “violin-shaped building in the style of Gaudi”.

Where Midjourney and other AI-generated art tools have set imaginations racing is in the more philosophical realm. How does Midjourney view “death” or “alone”?

For that matter, does Midjourney have self-consciousness? (Spoiler alert: the answer is definitely no.) But the similarities between the results for the prompts “Midjourney” and “you” do have me scratching my head. What caused the algorithm to make these choices?

The results for prompts “pivot”, “solstice” and “death” are eerie but feel like they could have been drawn by the same artist. What causes Midjourney to have a “style”?

To answer these and other questions, I visited SensiLab, based at Melbourne’s Monash University, where researchers use machine learning techniques to work on art projects.

Barely managing to move forward against the wind as I walked down Dandenong Road, I came upon the Monash Art Design and Architecture building. Entering the angular structure, I headed into SensiLab where I was greeted by IT professor Jon McCormack, who directs the work at the lab.

McCormack is quick to say AI isn’t creative, intelligent or artistic in any way.

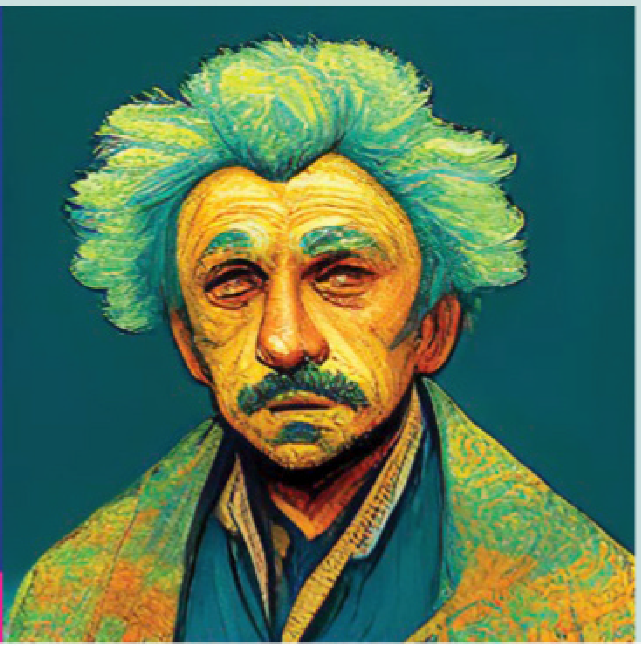
“I think artificial intelligence is a bit of a loaded term, because as soon as you say an AI is creating this, you assume that there’s some kind of intelligence there. If you actually look more carefully, you’ll find that there’s very little intelligence there at all. And it’s certainly not the kind of intelligence that we would associate with humans,” he says.

So, what does McCormack think of tools like DALL-E and Midjourney?

“They’re basically very big neural networks that have been trained on a huge volume of human imagery. I would call them parasitic in the sense that

[“Einstein by Monet”]

[“Einstein by Matisse”]



[“Einstein by Van Gogh”]

MIDJOURNEY

they’re not making anything, they’re just scraping huge amounts of data. I mean, they’re very clever and very sophisticated.

“They’re looking at statistical correspondences between features of images and text. So, you can type in a text prompt, and it will generate an image. That’s one of the big discoveries about deep learning neural networks that’s made them interesting from a creative point of view. Machines are capable of doing things that might inspire you. You might think there’s something creative going on. But these images are essentially ‘mashups’.”

It’s really more machine learning, McCormack stresses – there’s very little intelligence going on. He says that the way the machine responds might seem to us to be philosophical. But the software system itself doesn’t even have a concept of philosophy.

“It doesn’t have any sense of what meaning actually is,” McCormack says. “Whereas for humans, that’s something that’s fundamental to who we are; to our intelligence.

“So, if we’re going to call it intelligence, it’s not an intelligence that’s human. And it’s not like human intelligence at all. And I think that’s the mistake that people make, and that they tend to anthropomorphise.

> **It seems to be very profound. But really all it’s doing is just drawing on what people have done in the past.**

“It seems to be very profound. But really all it’s doing is just drawing on what people have done in the past and looking at statistical relationships between those things. In a sense, its power is that it’s been exposed to so much more than any single person could be exposed to in a lifetime. It’s got a sort of collective understanding of what imagery is, but only at the level of pixels, not at the level of emotion.”

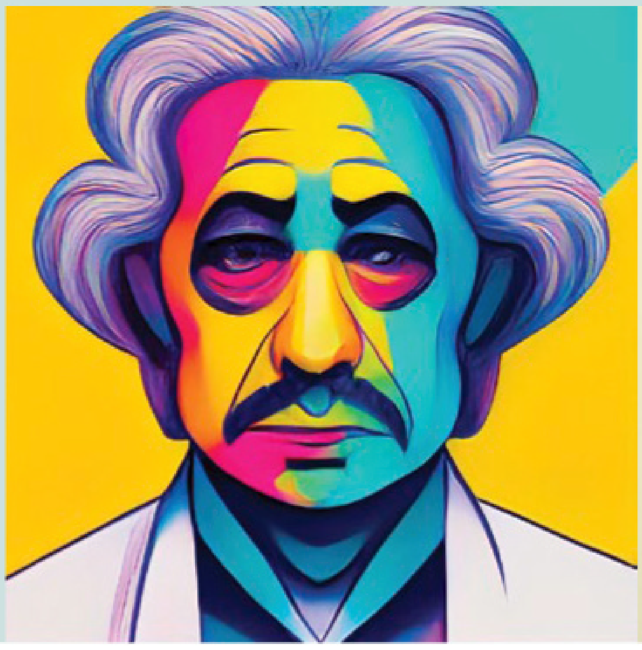
McCormack explains that the AI can’t understand all the things that we take for granted like proprioception, issues of embodiment, tactility, materiality – things that are very important in terms of artistic expression. It also lacks intention, he says. “The fact that you can type in a prompt and you get an image back is just a transactional relationship. It’s not an artistic relationship.

“These systems are kind of statistical mirrors on broad aspects of human culture. What’s interesting is that, of course, these images that have been synthesised now by programs like Midjourney, and DALL-E are becoming part of human culture as well.”

The SensiLab leader emphasises that he’s impressed with the technical feat that these imaging tools represent. “The technology will keep improving. These will become standard tools for people working in commercial design, for example. If you need an illustration for a story that you’re doing on artificial intelligence, for example, you can just type the prompt into Midourney or DALL-E and you can get a really nice image that you would have normally had to pay an illustrator for.”

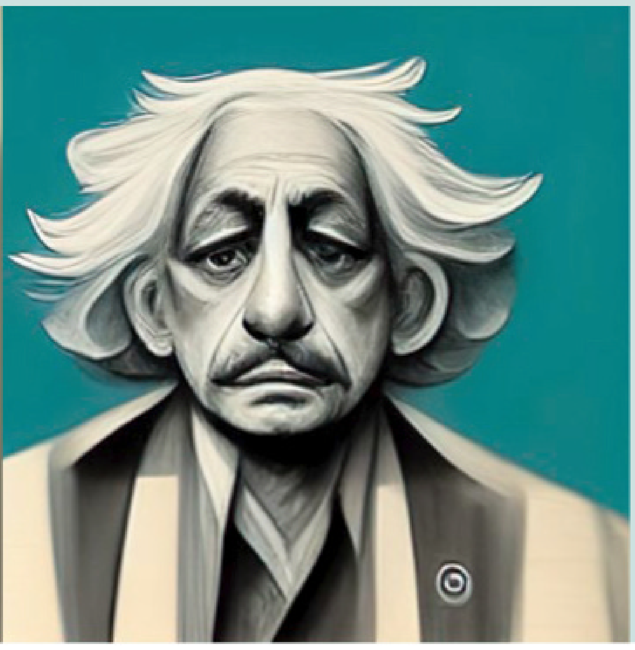
But McCormack doesn’t see AI tools replacing human artists. “I don’t see any rational – or even creative – reason to want to do that.”

The approach at SensiLab, he explains, is “much more about supporting and nurturing human creativity. A lot of the work we do is target



["Einstein by Warhol"]

["Einstein by Dali"]



["Einstein by Picasso"]

around what we call 'co-creativity'. So, working in collaboration with a machine to help you do something to sort of push you into certain signs of thinking or ways of thinking, to do things like inspire you, or give you ideas that you can take. But we don't think of the computer as being independently creative at all." McCormack stresses that anyone who makes that claim "is quite unjustified".

At first, SensiLab looks like any other computer laboratory, with a few rows of researchers tapping away at their keyboards. But, as McCormack shows me around, I quickly find myself immersed in the bits and pieces of projects strewn about. But who is doing the art at SensiLab? The AI or the human researchers?

Researchers do a lot of work in "computer music". In a corner of the lab is an electronic drum-kit. McCormack explains that team members found professional drummers to lay down beats on the kit to "teach" an AI program about drumming. The AI then produced its own drum beats, often playing in such a way that is indistinguishable from a human drummer, but sometimes playing things that were "a bit unusual".

McCormack shows me into a darkened studio with recording equipment splashed around. Off to one side is a large circular mirror on a stand. He explains that the mirror is an interactive AI-facilitated artwork. The AI 'reads' the emotion in a human face and produces a poem based on that emotion.

"We also do a lot of work in design and things like that," McCormack says. "It's more practically oriented than just making an artwork. So how can you design things that fit particular purposes or have a balance of things in terms of their aesthetics, functionality, material costs, and things like that."

SensiLab produces its hardware in-house as well. There is a room full of 3D printers and lidar machines as well as circuit board generators.

The lab has worked in collaboration with medical researchers and has accidentally come across tools to aid people with accessibility issues.

One story McCormack relays is about a dancer with cerebral palsy, which causes occasional muscle spasms. A machine learning tool developed at the lab was adapted to produce visualisations that learn from and reflect the dancer's actions. The tool, rather than trying to hide the spasms, leans on them and incorporates them into the artwork.

"The challenges are really understanding a person's creativity and their creative journey," McCormack explains. "Not everyone thinks creatively in the same way. And so it is that degree of personalisation and understanding.

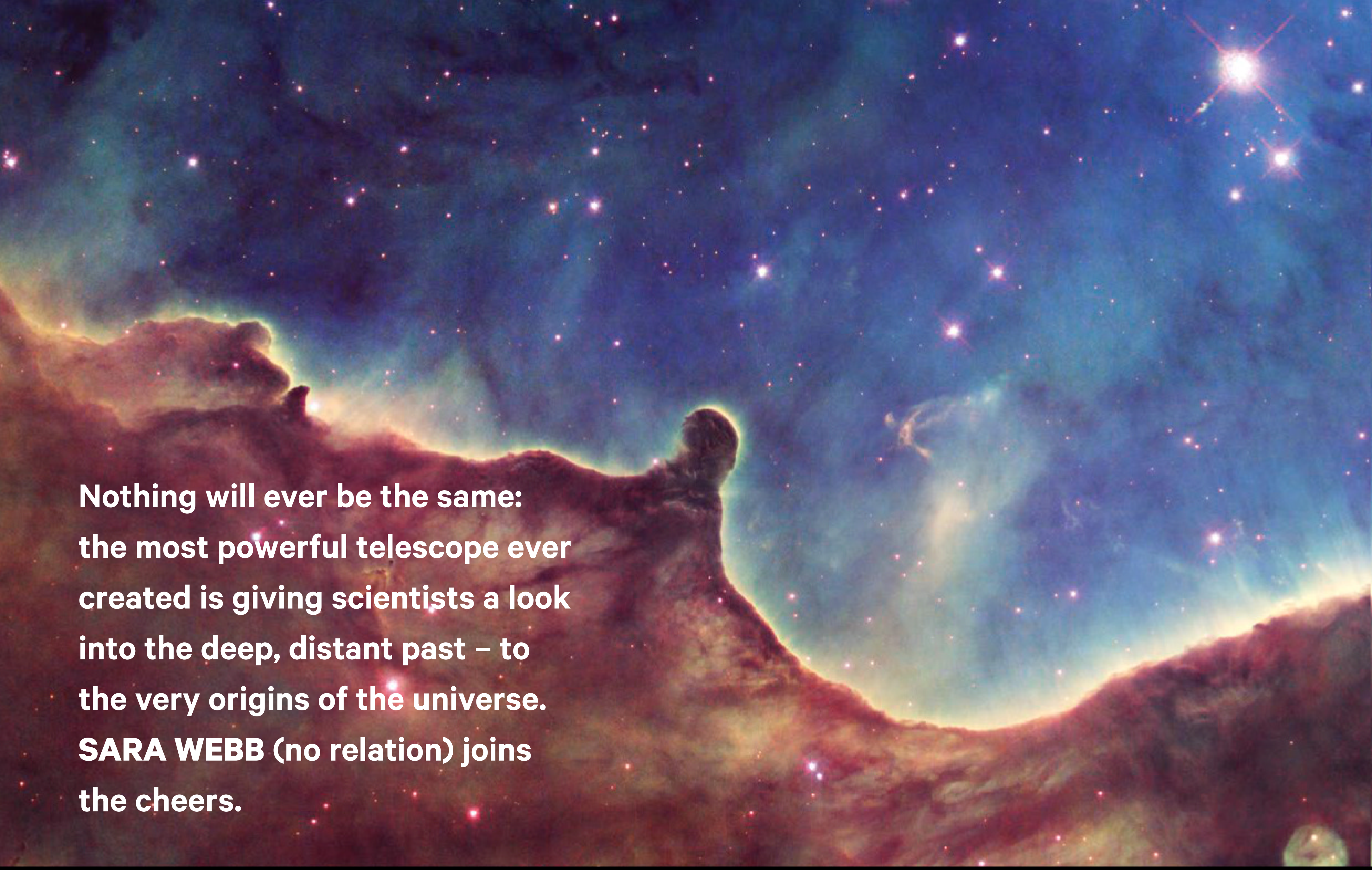
"That's the difference between a tool and a co-creator. A tool is something that you get given and you learn how to work with it. A hammer is a tool, and you can use [it] in all sorts of interesting and different ways. But the tool doesn't change, it's still just a hammer. Whereas with a co-creator, the co-creator learns about you and changes and adapts. I think that's what's really interesting is that you now have software that can learn and then can adapt and change.

"What people put into the software is not necessarily the limits of its capabilities. It's not just defined by what the person who programmed the software is able to imagine or conceive. The software can exceed that person's imagination because it can learn new things.

"And that's to me where it's quite exciting. And it's what it learns and how it learns and how it communicates that to a human co-creator, which is, I think, the area that we're really interested in."

An educational resource for this story is available at **www.education.riaus.org.au**

EVRIM YAZGIN is a science journalist at *Cosmos*. This is his first story for the magazine.



Nothing will ever be the same: the most powerful telescope ever created is giving scientists a look into the deep, distant past – to the very origins of the universe. **SARA WEBB** (no relation) joins the cheers.

A UNIVERSE

NASA, ESA, AND THE HUBBLE HERITAGE TEAM (STSCI/AURA)

SEEN BY WEBB

NASA, ESA, CSA, STSCI

NASA, ESA, AND THE HUBBLE HERITAGE (STSCI/AURA)-ESA/HUBBLE COLLABORATION

If you ask an astronomer, “Are time machines real?” you might be surprised to hear the response: “Of course!” Now, I’m sadly not talking about a big blue phone box (Dr you-know-who) or speedy DeLorean (back to you-know-when). Instead, I’m talking about telescopes. And the James Webb Space Telescope (JWST) is the most amazing time machine we’ve built yet.

Orbiting around the Sun at a distance of about 1.5 million kilometres from Earth, JWST is seeking to answer some of the biggest questions in science. What were the first stars? How do galaxies evolve? How do stars evolve and could there even be life out on distant exoplanets?

To do this, JWST uses the power of science to look back over billions of years of universal history.

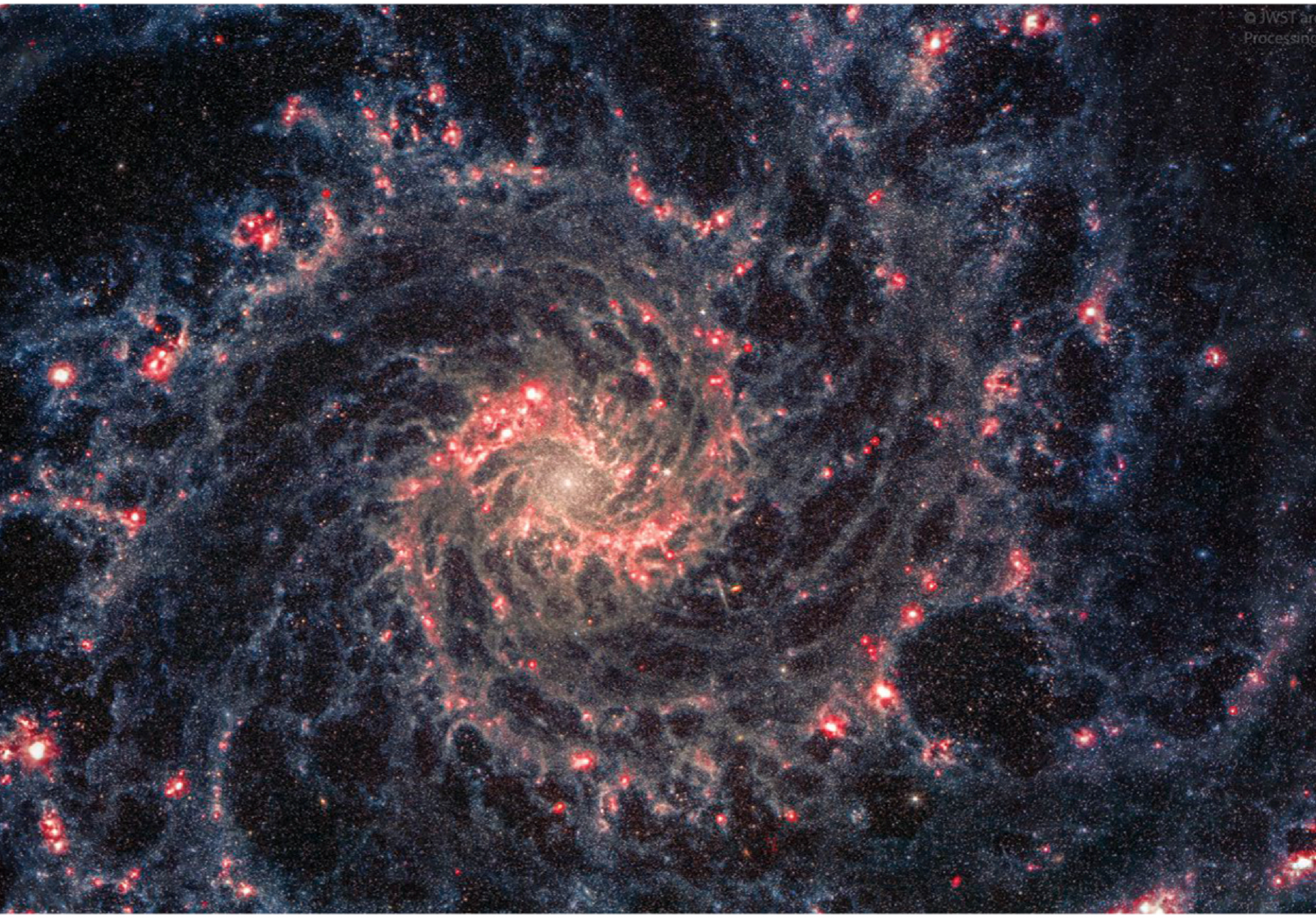
In this wonderful universe of ours, we have several laws of physics that govern throughout. One of these, and my personal favourite, is the speed of light. A universe can have a speed limit, and in our case it’s how fast light can travel in a vacuum. Light, no matter what its energy is, can only travel at the peak speed of 299,792,458 metres per second. Mighty fast from our perspective, but pretty slow across the grand scheme of the universe.

Before and after the James Webb Space Telescope (JWST): Viewed from the Hubble Space Telescope, the nearby galaxy NGC 628 (above) is a grand design spiral galaxy with symmetrical spiral arms dotted with clusters of young blue stars. A colourised combination of image datasets from JWST (opposite above) reveals in NGC 628 cooler stars and dusty structures only hinted at in earlier images. Previous pages: NGC 3324, in the Carina Nebula, is impressive enough (top) in the composite image built from Hubble data. Seen from a JWST image (bottom), previously obscured areas of star birth are revealed in stunning detail.

Every time we look up at the night sky, we are looking back in time to space as it once was. Even our own Sun appears as it was a whole eight minutes earlier. For our brightest stars, this time gap might only be a few hundreds or thousands of years back in time. But for distant galaxies, it can be billions and billions of years. This is what JWST was built to do: to look back into time, like never before, and unveil the beginnings of our universe.

As we see it from Earth with our own eyes, the night sky is only the tip of the iceberg. Our galaxy and the galaxies beyond it often need much better ‘eyes’ than our own – these come in the form of specialised telescopes, which can see different types of light to our visible spectrum. To really get 20/20 vision, we need to leave the fuzz of our atmosphere behind. JWST does just this. It allows us to peel back how galaxies looked and evolved, right back to the beginning.

To see light from very distant galaxies, we need a very large collecting area. As light travels through space, it follows yet another law: it decreases in brightness



over the amount of space it has spread into. We can visualise how this works when we use a flashlight: the beam spreads out but appears to look fainter the further away it is. This is exactly what is happening on universal scales. The incredible mirror of JWST is designed to try to capture as much of that distant light as possible.

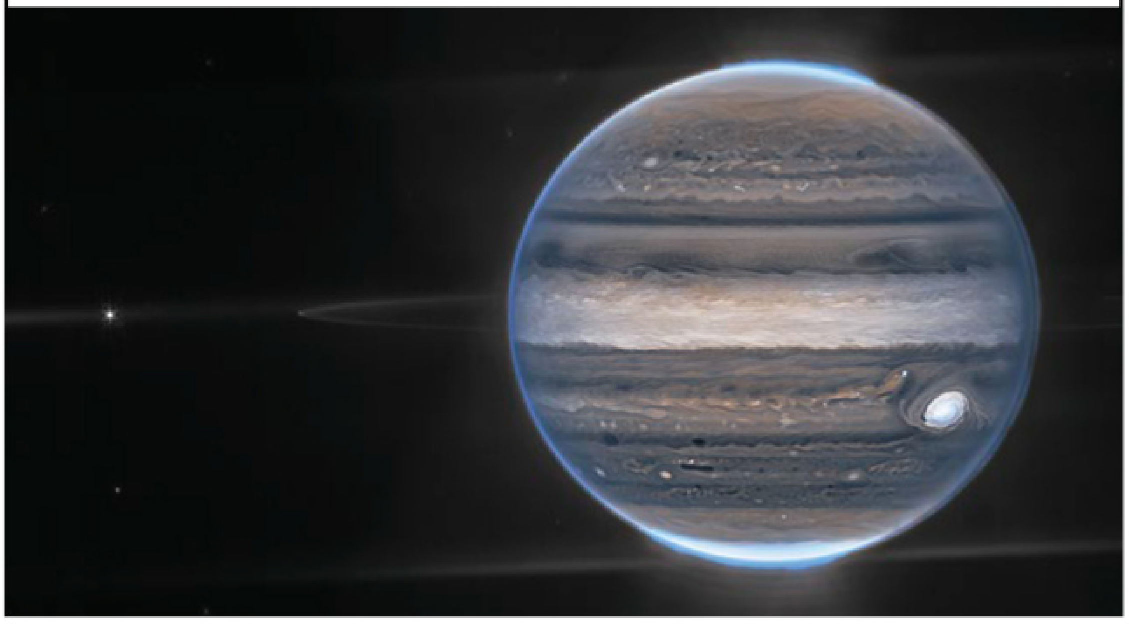
JWST's beautifully complex mirror measures a massive 6.5 metres across and is composed of 18 gold hexagonal-shaped segments. They're not just gold in appearance: they're actually covered in a microscopically thin layer of gold. This layer is key for optimising how much infrared light can be reflected into the camera. The JWST mirror can reflect around 99% of the infrared light that hits it, meaning it has excellent infrared eyes in space. JWST is about 100 times more powerful than the mighty Hubble Space Telescope. Pretty impressive!

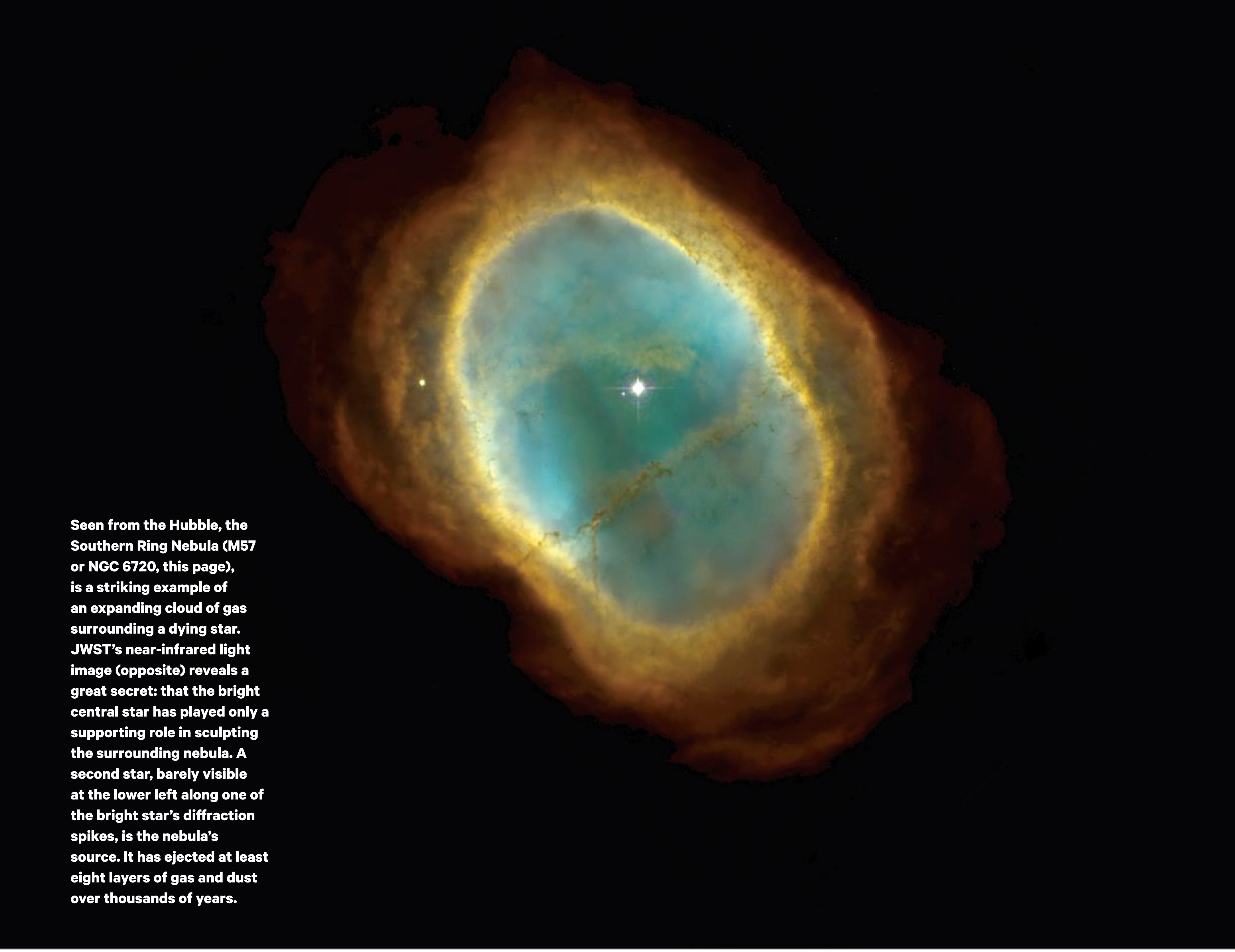
Are you wondering why infrared light? There are a few reasons. First, the amount of infrared light we can see here on the Earth is very limited. Our atmosphere emits infrared light and is effectively opaque to that coming from space. Second, and the most important reason, is that in the very distant universe infrared

NASA, ESA, CSA, STSCI; PROCESSING COPYRIGHT: ROBERT EDER

JUPITER BY JWST

In this wide-field view, JWST sees Jupiter with its faint rings, which are a million times fainter than the planet, and, to the left, two tiny moons called Amalthea and Adrastea. The fuzzy spots in the lower background are likely galaxies 'photobombing' this Jovian view – a composite image from JWST's NIRCam instrument acquired on 27 July 2022.

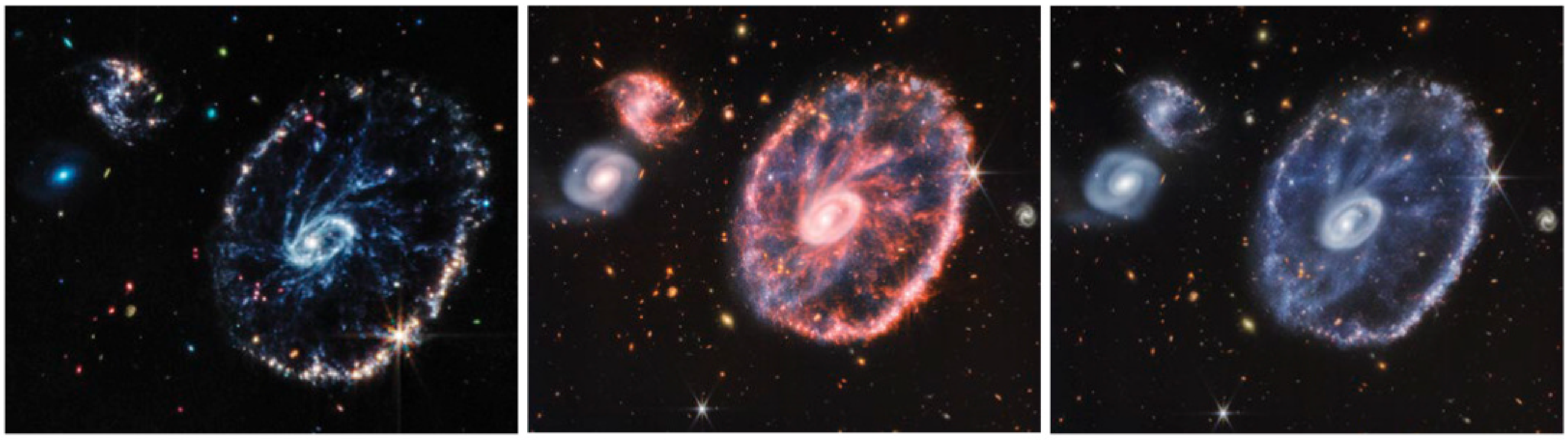




Seen from the Hubble, the Southern Ring Nebula (M57 or NGC 6720, this page), is a striking example of an expanding cloud of gas surrounding a dying star. JWST's near-infrared light image (opposite) reveals a great secret: that the bright central star has played only a supporting role in sculpting the surrounding nebula. A second star, barely visible at the lower left along one of the bright star's diffraction spikes, is the nebula's source. It has ejected at least eight layers of gas and dust over thousands of years.

CARTWHEEL GALAXY: LAYERED INFORMATION

JWST doesn't collect data in the visible colour spectrum we know. Instead, different instruments collect different information, which can be combined as required. The Cartwheel Galaxy is composed of a bright inner ring and active outer ring, with a dusty area in between that reveals many stars and star clusters. JWST's Mid-Infrared Instrument (MIRI) captures light (below left) that reveals fine details about the dusty regions and the galaxy's young stars. The telescope's Near-Infrared Camera (NIRCam) data (below right) help define the difference between the older star populations and dense dust in the core and the younger star populations outside of it. A composite (below centre) of MIRI (coloured red) and NIRCam (blue, orange and yellow) data reveals details that are difficult to see in the individual images alone. Amid the red swirls of dust, there are many individual blue dots, which represent individual stars or pockets of star formation.



(ABOVE): HUBBLE HERITAGE TEAM (STSCI/AURA/NASA/ESA)
(LEFT): NASA, ESA, CSA, STSCI, WEBB ERO PRODUCTION TEAM

IMAGE: NASA, ESA, CSA, STSCI

Hear what's making news in science in Australia and across the globe every Tuesday and Thursday on *The Science Briefing*

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light is all that's visible, all thanks to something called cosmological redshifting.

For almost 100 years now, we've appreciated that the universe was so much bigger than our 'home' Milky Way galaxy. In the 1920s Edwin Hubble worked tirelessly to estimate the distances to our extragalactic neighbours, but he made a puzzling discovery along the way.

He found that not only were galaxies moving away from us, but the further away the galaxy was, the faster we were moving from it… meaning the universe was expanding. This is the reason we need JWST to 'see' in the infrared.

What's causing the universe to expand is dark energy – a cosmic conundrum to cover another time. For now, we just need to know that the universe is constantly getting bigger, and that this expansion of space does a pretty awesome thing to light: it stretches it!

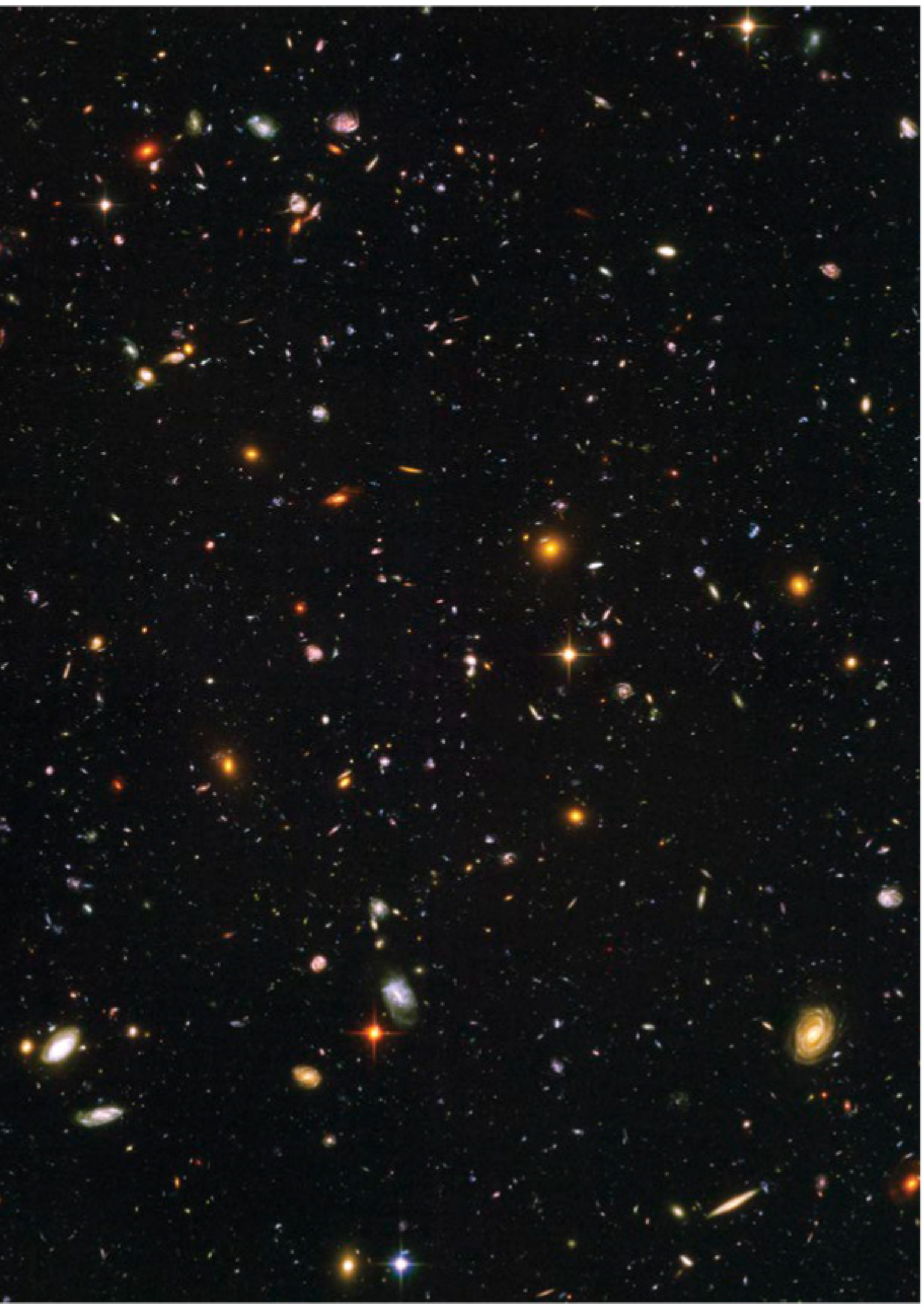
Light which began blue will turn red over time. This is due to energy loss and it happens across the entire electromagnetic spectrum. In the local universe, the redshifting of galaxies is enough to detect only small shifts towards the redder wavelengths. In the distant universe, the effects become apparent. Whole galaxies seem to 'disappear' in visible and UV wavelengths at a certain distance. That light is still there, but now mainly in the infrared. This is where JWST can shine, as it can capture galaxies that Hubble never physically could.

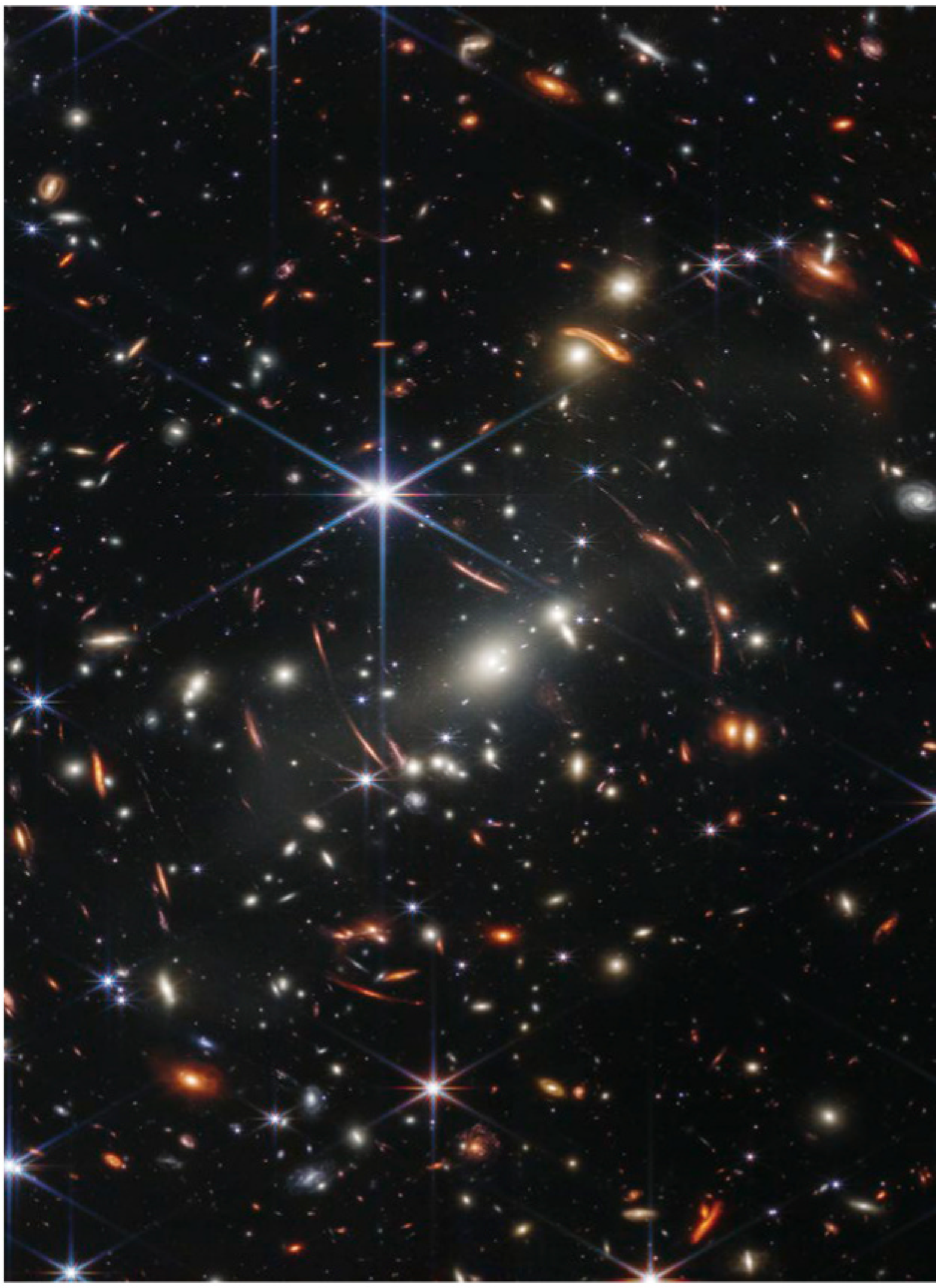
And *wow*. JWST has already outdone all our expectations.

In the first images released, the thing astronomers were most excited about wasn't the beautiful big galaxies – it was the almost-invisible tiny dots in the background. To astronomers, these small points of light are like the best gift the universe could give us. They are the most distant galaxies in our observable universe.

Just from those first few images, we already have a handful of candidate galaxies ready to take the crown for the most distant galaxy. If these galaxies are confirmed, their light is well over 13.5 billion years old. Emitted only a few hundred million years after the beginning of the universe, the light in these galaxies is most likely from the first-ever stars, ones made entirely of hydrogen and helium.

What's truly mind-blowing about these first galaxies is how far away from us they now are. The light has





A view of nearly 10,000 galaxies (above left), the Hubble Ultra Deep Field image is composed of 800 exposures taken during 400 Hubble Earth orbits with a total exposure time of 11.3 days. The exposures were taken between September 2003 and January 2004. JWST's First Deep Field (above right), captured this year, shows galaxy cluster SMACS 0723 as it appeared 4.6 billion years ago. The image covers a patch of sky approximately the size of a grain of sand held at arm's length by someone on Earth. It reveals thousands of galaxies in a tiny sliver of vast universe – including the faintest objects ever observed in the infrared, by JWST's NIRCam. This breathtaking deep field is a composite of images taken at different wavelengths, with a total exposure time of just 12.5 hours. "And this is only the beginning," says NASA. "Researchers will continue to use Webb to take longer exposures, revealing more of our vast universe."

taken 13.5 billion years to reach this side of the universe, but those galaxies are much farther away than that. Due to dark energy accelerating the expansion of the universe, these distant galaxies now sit 35+ billion light years away.

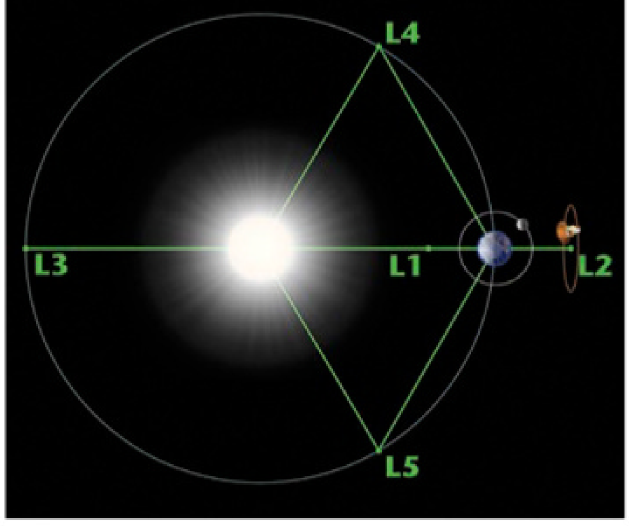
JWST allows us to travel that expanse of space and time. It allows us to 'see' regions of galaxies that were once 'invisible' to us. Infrared light is an exceptional probe of dust in galaxies. This is because galactic dust is very good at absorbing and scattering blue light and emitting redder light.

The best example of this is the breathtaking image of the unassuming galaxy NGC 628 (page 81). Previous Hubble images of this galaxy had people in awe of its perfect spiral structure. JWST's infrared images of this galaxy left us speechless. It looks like a portal to another universe, or a gate to another dimension. The spiral structure was so much more detailed than we could ever have imagined. By probing the light from dust and gas, JWST can give a different perspective on the galaxies we once thought we knew well.

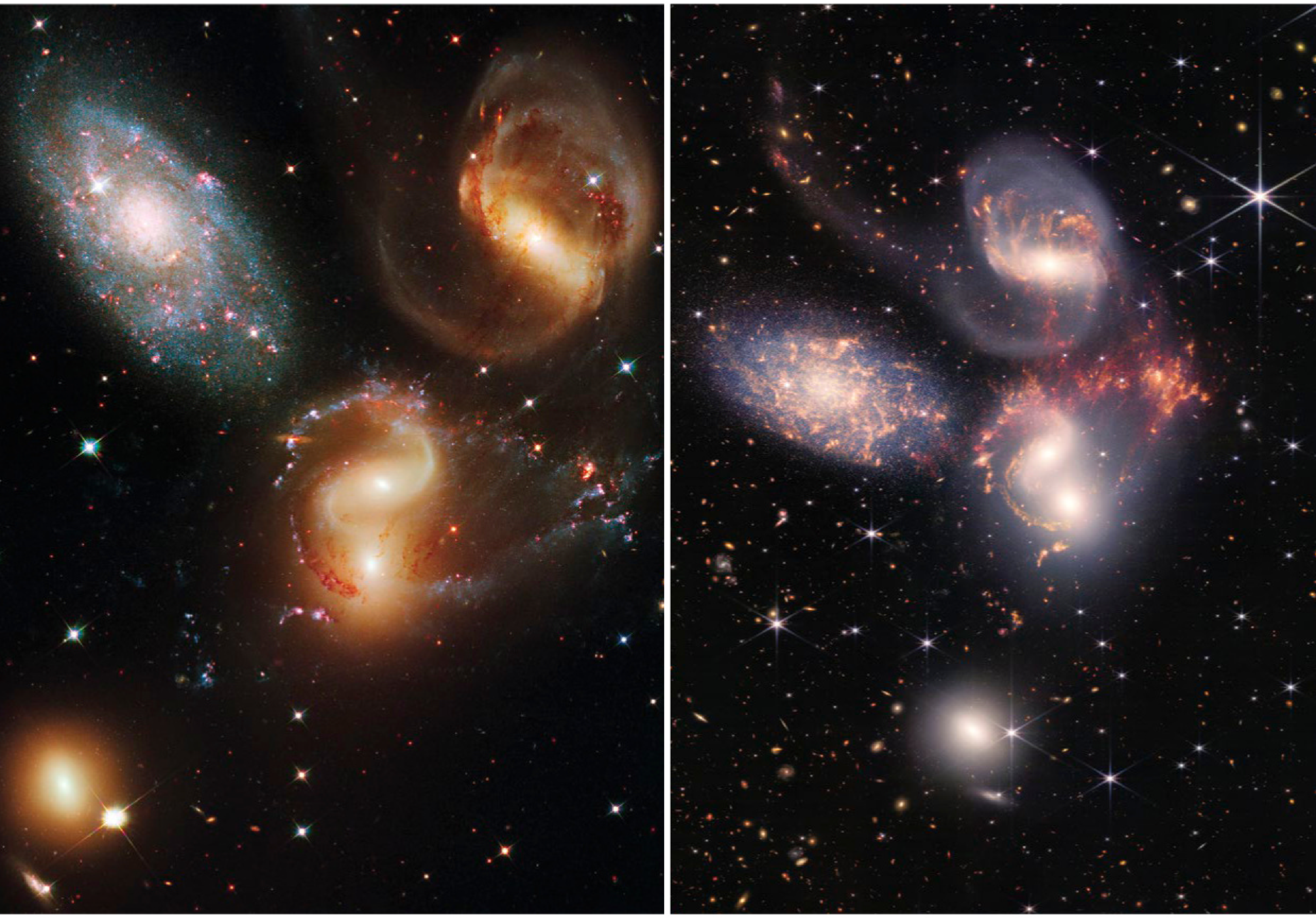
It is even providing us better insight into our very own galaxy, revealing to us areas that we've

HOME, HOME ON LAGRANGE

Like its predecessor, the Gaia Space Telescope, JWST is in a controlled orbit around the L2 Lagrange point – one of five such points where the competing gravitational pull of Earth and the Sun hold a satellite relatively stable. It's positioned approximately 1.5 million kilometres beyond Earth's solar orbit.



(ABOVE LEFT): NASA, ESA, AND S. BECKWITH (STSCI) AND THE HUDF TEAM
(ABOVE RIGHT): NASA, ESA, CSA, AND STSCI



Captured by Hubble in 2009, the galaxy group Stephan's Quintet (above left), located in the constellation Pegasus, seems to stack up well against JWST's image (above right) released in July. But using its powerful infrared vision and extremely high spatial resolution, JWST shows never-before-seen details in the group, such as sparkling clusters of millions of young stars and starburst regions of fresh star birth, and sweeping tails of gas, dust and stars being pulled from several of the galaxies due to gravitational interactions. Most dramatically, JWST's MIRI captures huge shock waves as one of the galaxies, NGC 7318B, smashes through the cluster. These regions surrounding the central pair of galaxies are shown in the colours red and gold.

(ABOVE LEFT): NASA, ESA, AND THE HUBBLE SM4 ERO TEAM
(ABOVE RIGHT): NASA, ESA, CSA, AND STSCI

only previously dreamt of seeing. The Carina Nebula (page 78) was captured with all the power of JWST and it's nothing short of absolutely spectacular. It's my favourite space image, ever. This image of the cosmic cliffs uncovers hundreds of previously unknown stars – those newly formed in this enormous stellar nursery. The amount of dust and gas in nebulas like these makes them effectively opaque to optical telescopes. Being able to peer behind the dust in complex areas like this in the Milky Way will help us better understand the birth and evolution of stars.

This is only the very beginning of the incredible science to come from JWST. The minimum mission time will be five years, but NASA has an exceptional track record of missions outdoing their expected lifetimes. Hubble, designed for a 10- to 15-year mission, has been in orbit since 1990, and is still going strong 32 years later.

There are four main science themes of the JWST mission: Early Universe, Galaxies Over Time, Star Lifecycle, and Other Worlds. Within these four umbrella science themes, JWST will help us uncover the secrets of the universe. These questions will be investigated around the world, with thousands of scientists involved in 14 countries.

Here in Australia we have our very own superstar astronomers already working hard on this data. Professor Karl Glazebrook is leading a team out of Swinburne University of Technology to use machine learning and artificial intelligence to quickly work through the mountains of data to come, looking at galaxies and how they formed in the very early universe. Dr Benjamin Pope from the University of Queensland is working on an entirely different science goal, studying dead stars, planets and even asteroids with new and exciting techniques.

We are already seeing an incredible amount of JWST-prompted science appearing in pre-print on arXiv, and the competition for most distant galaxy is nowhere near over. And we can look forward to seeing results soon from the many other amazing projects currently ongoing. What a time to be alive! ⊙

SARA WEBB is a postdoctoral researcher at Swinburne University of Technology. This is her first story for *Cosmos*.

MAN AS THEP / ADOBE STOCK

GREEN SEAT

The effort to enshrine rights for the future into a new Chilean constitution was a remarkable attempt at transformation. Now **CLARE WATSON** reports on what we can learn.

Monserrat Madariaga Gómez de Cuenca, a Chilean environmental lawyer, has been watching her country reinvent itself.

Over the past year, more than 150 elected representatives, including a microbiologist and several Indigenous leaders, had been hard at it nutting out a new constitution for their country – the most progressive constitution to be drafted in the midst of the climate emergency.

Nearly 80% of Chileans voted in October 2020 to reimagine their country's governing principles after massive protests erupted a year earlier, denouncing deep social and economic inequities in the country.

Increasing water scarcity was also the product of the country's extractive-mining-led economy, and Chileans had finally realised "we are damaging the environment for the benefit of very few", said Madariaga, now at University College London. "People [were] saying enough is enough."

On 4 September, Chileans voted in a plebiscite to reject the newly drafted constitution. Have they denied themselves a fairer future?

Principally, the draft constitution recognised runaway climate change as an "ecological and climate crisis" that could only be addressed through far-reaching policies and laws. It expanded environmental protections and aimed to safeguard the livelihoods of future generations.

It also stated that the Chilean government had to guarantee that its citizens had access to clean air, water and adequate food. Moreover, the state would have had a constitutional duty to combat climate change and to conserve the country's rich biodiversity, vast deserts, stunning alpine lands, windswept oceans, wild forests, wetlands and Patagonian glaciers.

Before the vote, Madariaga said the proposed constitution would change everything about Chileans' relationship with nature.

Chile is one of the world's top exporters of lithium and copper, and those mining industries have extracted vast amounts of water from a drought-stricken landscape. That water is bought and sold in a privatised water system, which would have been struck down had the new constitution been approved. What will happen now is uncertain.

Not all hope is lost. Pre-plebiscite, Madariaga said that Chile was "moving forward with regulatory instruments related to climate change as never before".

The country has already passed a new climate change law that binds it to carbon neutrality by 2050, and which could see Chile set enforceable emissions caps on the mining industry, an effort spearheaded by the newly elected environment minister, Maisa Rojas.

Rojas is an atmospheric physicist and one of hundreds of scientists who co-authored the Intergovernmental Panel on Climate Change's (IPCC) 2021-22 report that, in three instalments, issued a "code red for humanity".

"It's this moment where you think that everything [which] is not possible when you don't have the political will, could be possible now," said Madariaga of the draft constitution.

The process to rewrite Chile's constitution was a slow and at times bumbling democratic process. But it yielded a bold vision born out of some of the country's darkest times, according to Madariaga.

Diego Mardones, an astronomer at the University of Chile (who had campaigned to be an elected member of the constitutional assembly, but was unsuccessful), said the plebiscite was a truly unique moment in the country's history, one that he and many others hoped would rewrite the social contract between the Chilean government and its people.

At its core, the proposed constitution recognised principles such as intergenerational equity and just climate action, meaning the Chilean government would have had a duty to protect the rights of its youngest citizens – who've contributed least to climate change but will have to endure it – to live on a healthy, hospitable planet.

The constitution would also have given greater autonomy to local Indigenous communities that are fighting against exploitative mining practices on their ancestral lands.

"Making those communities more empowered to determine what's going to happen in their own territories should put a limit to the exploitation of nature," explained Madariaga.

Read more like this at
thecosmosweekly.com
Where the rubber of science meets the real-world road.

In total, around 50 of the 499 provisions of the draft constitution concerned environmental and climate issues.

University of Antofagasta microbiologist Cristina Dorador told *The Washington Post* in July that drafting had been "an unprecedented process, because we were able to consider all of the evidence around climate change when crafting the new constitution".

Dorador, who became the leading scientific voice in Chile's constitutional assembly and in the lead up to the September vote, usually studies extremophiles that live beneath the country's fragile salt flats.

She, like many other Chileans, hoped Chile's efforts to rewrite its relationship with nature could serve as an example to other countries – not only those in Latin America, but also others that have built their economies on extractive industries mining finite resources that are now facing critical water shortages – to strengthen their own environmental laws.

Even before the new constitution was rejected, the outlook was grim. A 2022 study suggests that even under the quickest emissions reduction trajectory modelled by the IPCC, southwestern South America will face higher odds of brutal and unprecedented droughts over the next 30 years.

"Chile dries up and will continue to dry, [so] we need to address the climate and ecological crisis in a comprehensive, equitable and democratic way," Dorador has tweeted.

More specifically, the draft constitution spelled out that the Chilean government was responsible for preventing, adapting and mitigating the risks, vulnerabilities and effects caused by the climate crisis.

Madariaga explained that a yes vote on the constitution would have been a direct mandate to create law and policy in order to comply with that [constitutional] duty. Had it been approved and implemented, the constitution would also have been a broadly "blooming moment for environmental policy and environmental law", she said.

The proposed constitution granted rights to nature itself, which would have given Chileans the legal tools to hold their government and private companies to account in the event they breached the people's right to nature, clean air and water. An ombudsman for nature would have been in charge of defending nature and enforcing its rights.

MARCELO HERNANDEZ / GETTY IMAGES

> “IT’S THIS MOMENT WHERE YOU THINK THAT EVERYTHING [WHICH] IS NOT POSSIBLE WHEN YOU DON’T HAVE THE POLITICAL WILL COULD BE POSSIBLE NOW.”

It could also have been a moment of huge possibility for scientific research since the draft constitution added science to Chilean public education and encouraged industry to innovate as the world moves towards a clean energy future, said Mardones.

Before the vote, Mardones said that if the new constitution was adopted and enacted, “[Chile] would be true worldwide leaders in many, many things”.

Madariaga said that countries like Australia could also learn from Chile and strive for better representation of women and Indigenous peoples. The make-up of the constitutional assembly, which had gender parity in its elected representatives, is “one of the most valuable lessons”, she said.

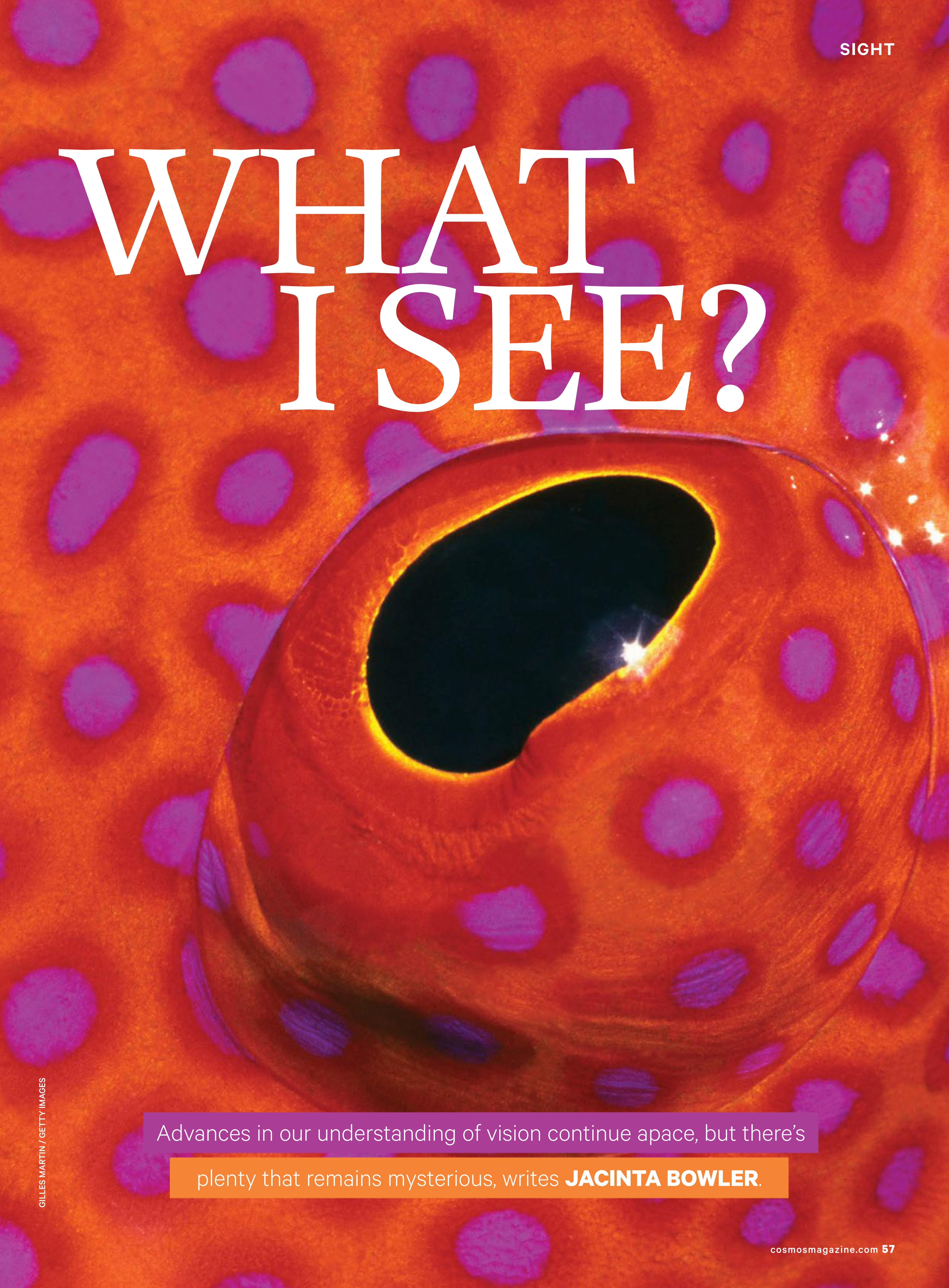
“That’s a brave act, but it’s also smart,” said Bradley Moggridge, a Kamilaroi water scientist and University of Canberra hydrogeologist, of the draft constitution and the diverse assembly that wrote it.

“Having Indigenous people at the table, [with] their knowledge and their connection to Country, and giving the environment, waterways and groundwater systems the right to exist and be protected, that’s going to benefit human society if [those systems] are healthy.” ◉

CLARE WATSON is a freelance science journalist based in Wollongong, NSW, specialising in health, medicine and the environment. This is her first story in *Cosmos*.

DO YOU SEE

MRIYA WILDLIFE / GETTY IMAGES



WHAT I SEE?

Advances in our understanding of vision continue apace, but there's plenty that remains mysterious, writes **JACINTA BOWLER**.

GILLES MARTIN / GETTY IMAGES

Imagine that you're deep in Costa Rican lowland rainforest, it's raining by the bucketload per square metre – and it seems as if the ground is practically bleeding frogs. You stop by a particularly handsome species; let's say it's *Agalychnis callidryas*, the gorgeous red-eyed tree frog. You gaze into its eyes and… what the? What you don't see staring back at you are the round pupils you're used to.

Turns out frogs can sport a wide variety of pupil shapes – from fans and triangles to horizontal and vertical slits, and sometimes all forms are present in the same taxonomic family.

Dr Rayna Bell, a herpetology researcher at the California Academy of Sciences, recently published a paper in the *Biological Journal of the Linnean Society* looking at why there's so much diversity in just one animal type. Her conclusions are the scientific equivalent of a shrug emoji. "It definitely asks more questions than it answers, but I think it's a good foundation, for now at least," Bell says.

Given humans' perfectly circular pupils, it might be a little hard to imagine the diversity of shapes we're talking about here. In dark conditions – when the iris is relaxed or dilated – most frogs' eyes look pretty circular. But when there's light, the iris constricts in weird and wonderful ways.

For example, the common eastern froglet's (*Crinia signifera*) pupils become like an upside-down triangle, while the giant barred frog's (*Mixophyes iteratus*) looks more like a cat's eye or diamond shape. Both of these frogs are Australian, are part of the same taxonomic family and live in similar environments. Why one evolved diamonds and one triangles is unknown.

This occurs across the amphibian kingdom, as the researchers on Bell's paper discovered. They analysed photos from 1294 adult species of amphibians, and the larval stage for 56 families of frogs and salamanders. The team then categorised the eye-weirdness into three main shapes: symmetrical, vertically elongated and horizontally elongated. Additional categories include diamonds and upside-down tears.

"It's maybe not as straightforward as you would like because shape is continuous," says Bell. "We tried to bin continuous variation into categories just so that it's more tractable, and so we can do analyses and quantify things.

"There's a lot of diversity out there, but mostly we don't really know for any group [of animals] why their pupil is shaped the way that it is."

The known unknowns

That lack of clear resolution didn't stop Bell and her team discovering some interesting things.

First, pupils regularly changed from when the species was a tadpole to when it was a frog if the different stages occupied different habitats.

"In addition, non-elongated [circle or diamond] constricted pupils were associated with species inhabiting aquatic or underground environments and elongated pupils [with vertical or horizontal long axes] were more common in species with larger absolute eye sizes," the team writes in its study.

This is an observational study and so there are no real conclusive answers, but the team's thesis is that larger eyes let in more light – particularly in dim conditions.

"Because a lot of frogs are active in moonlight, that's when they're doing their most important behaviours, like looking for mates and looking for food," says Bell. "We think they're investing really heavily in their eye size."

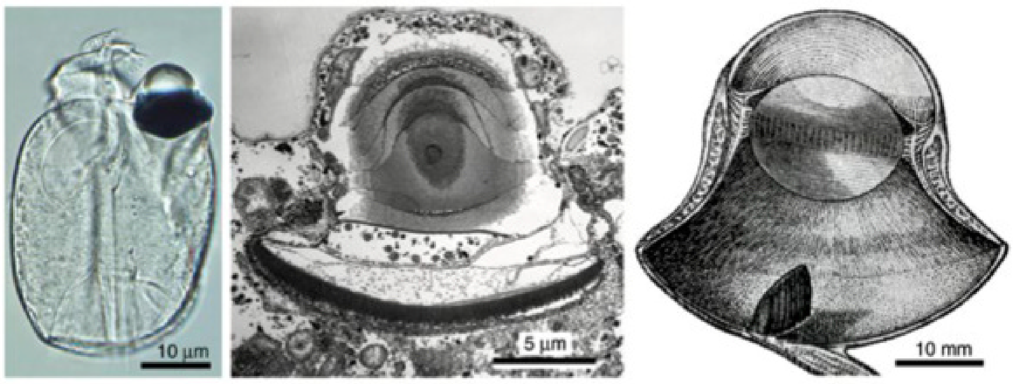
But large eyes and lots of light isn't as ideal during the day, when eyes can be overwhelmed with light. That's when elongated pupils come in: they allow the frogs to make their pupil size smaller, so they're capable of seeing even in lighter environments.

Last, other researchers have suggested that tree frogs and other frogs which spend much of their lives hanging from trees might have horizontal pupil slits – the equivalent of having vertical slits if the frog was on the ground the right way up. Unfortunately, the new research found no association of the sort.

This is just the tip of the research iceberg – Bell suggests that the paper allows other teams of researchers to look at where diversity is concentrated on the frog evolutionary tree. Researchers will be able to pick frogs in the same family but with different shaped eyes – like the common eastern froglet and giant barred frog – to study further.

This isn't the first study trying to investigate why frogs' pupil shapes are just so weird. Another study, published last year in the *Proceedings of the Royal Society B,* found even less evolutionary reasoning.

ALGAE WITH EYES?

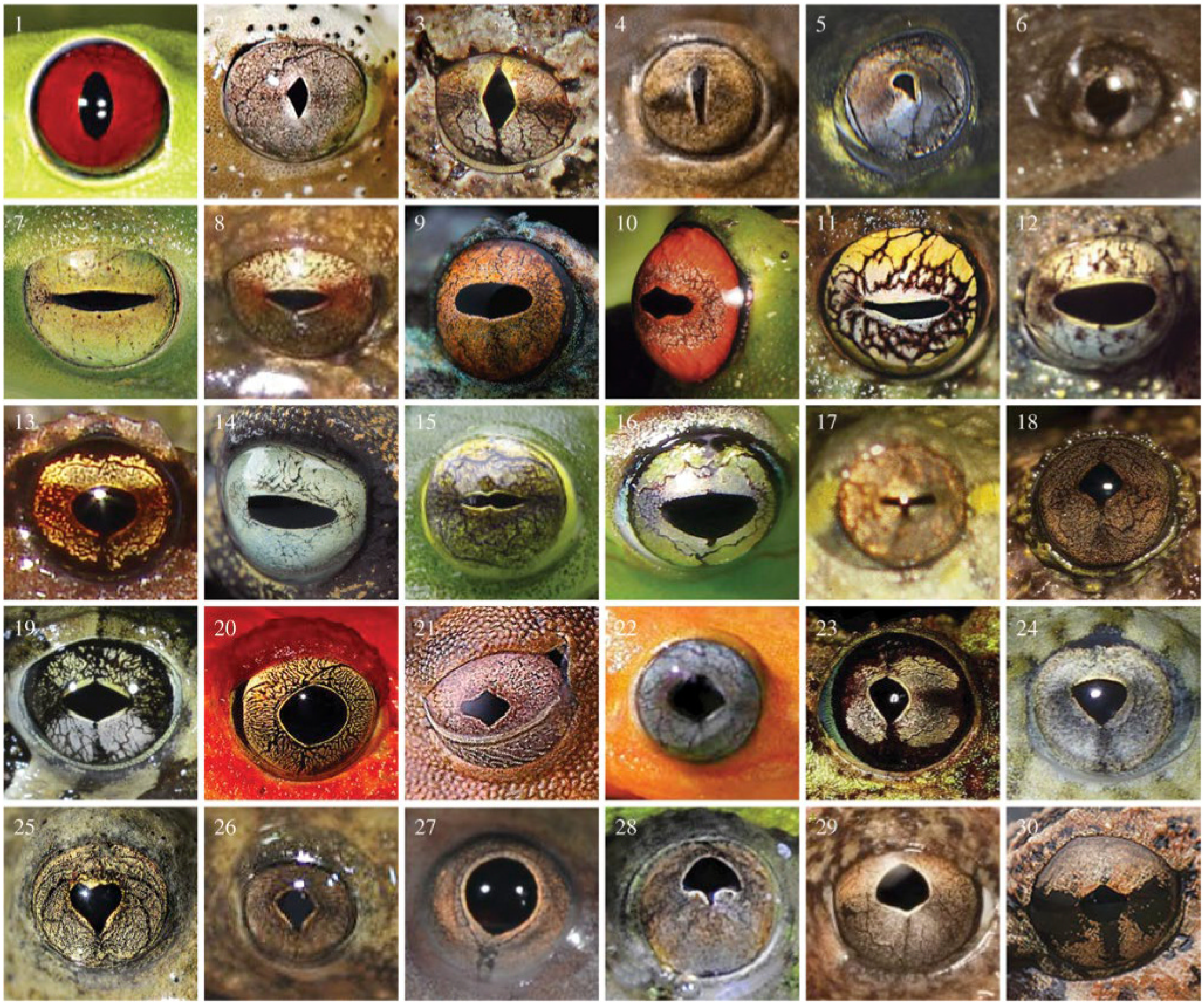


Single-celled warnowiid dinoflagellates – like *Erythropsidinium*, left – are usually thought to be algae. So why does it have an eye-like structure, centre, called an ocelloid? Can it see? It closely resembles an eagle owl's eye, right.

F. GÓMEZ, T. GOJOBORI, CRANBROOK INSTITUTE OF SCIENCE

LOOK INTO MY EYES ...

Around the world, frog pupil shapes and sizes reveal dazzling variety. Pupil shapes vary from diamonds (3, 6, 18) and hearts (25) to keyholes (5) and the distinctly alien. Why such astonishing diversity? "We simply don't know," says Julian Faivovich, author of a frog eye study published last year in *Proceedings of the Royal Society B*.



THE ROYAL SOCIETY

"We simply don't know," one of the paper's lead authors, Julian Faivovich, says. "Our research was a first step to put all the data together, infer the main evolutionary patterns, and try to find out if there were any evident explanation for pupil diversity considering the multiple habits of frogs – and [we] found almost none!"

Here's the thing, though: frogs are notoriously shy creatures. You're much more likely to hear a frog than see it, and it's even harder to analyse its pupil shape from just a few photos.

More research might allow scientists to physically do research – either genetically or experimentally – to work out why frogs have myriad mesmerising peepers.

But much more research has been done on a creature much closer to home: humans. So, why are our pupils circular, and what are we still not understanding about our own eyes?

Windows to the soul

Ask Associate Professor Andrew Metha, head of Optometry and Vision Sciences at the University of Melbourne, about why human pupils are circular, and you may be surprised when he starts talking about quantum mechanics.

"I think this comes fundamentally down to the quantum nature of light sometimes behaving like particles or like a wave," he says.

This idea – that vision is just physics wrapped in an imperfect biological meat shell is not as controversial as it sounds. Darwin himself had to wrestle with the notion that a 'perfect organ' like the eye could evolve through random chance and selective pressure.

"If we've got two working eyes, when we look at our fingers, we can know which finger is in front of another finger," Metha says. "So, our awareness of not just two-dimensional space but three-dimensional space within arm's reach is very special for humans – and it's allowed us to be a tool maker."

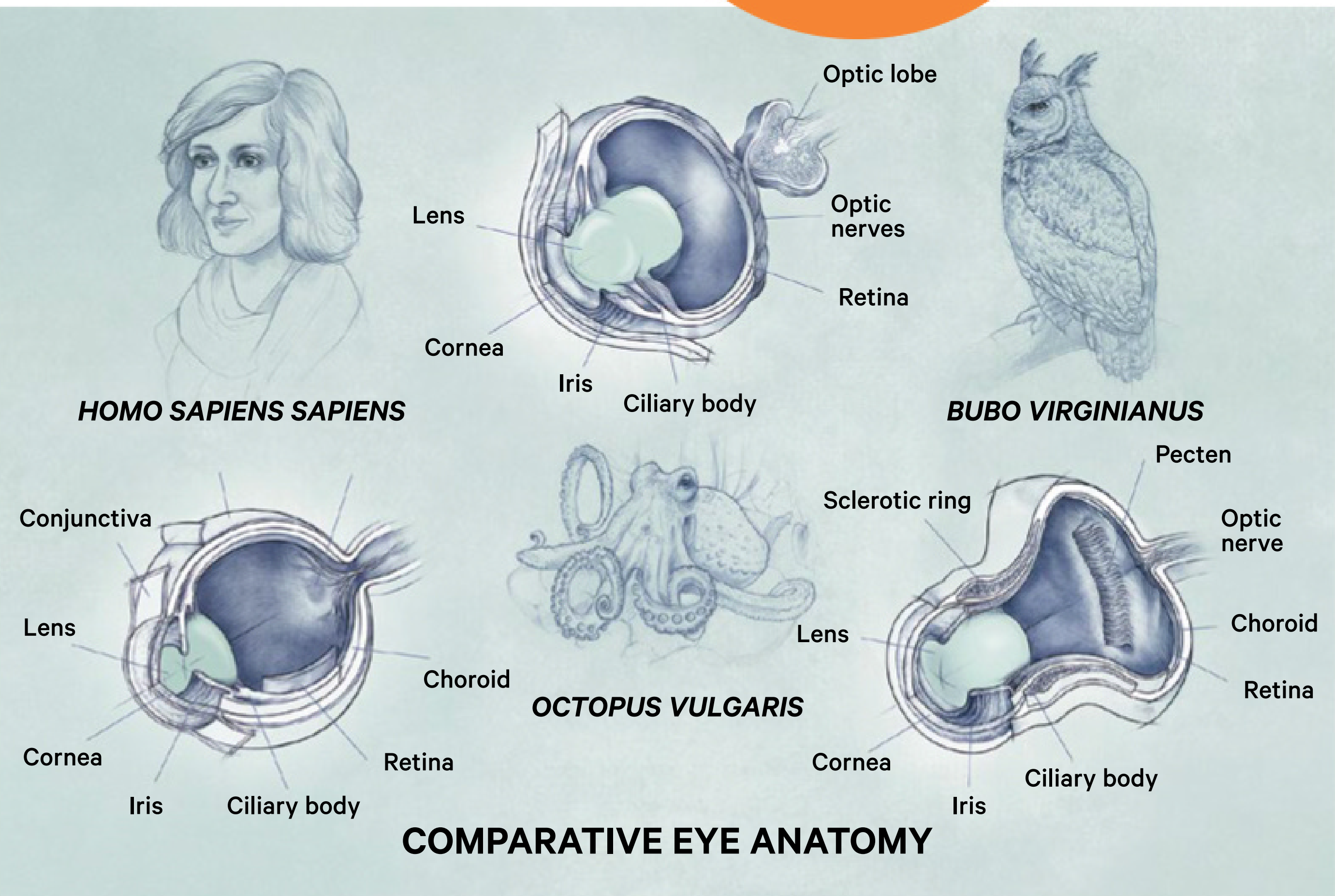
If you had your hands on a human eye, even without opening it up it's easy to see the orb-shaped organ has two important areas – the front and the back.

At the front of the eye there's the iris – a coloured sphincter that dilates and contracts depending on how much light is present. The black space in the middle is the pupil, followed by the lens suspended by ligaments. Above the whole thing there's a bump in the orb where the protective cornea and some extra liquid sit.

If you flip the whole thing over there's a bundle of nerves that exit out the back of the eye and enter the brain. Although you wouldn't be able to see most of it without cutting through the outer layer, the back houses the retina, the optical disc, and (in some, but not all, species) a fovea, which is packed with cone photoreceptors to help give us our sharp central vision.

FIT FOR PURPOSE

Owls' tube-like eyes help with low-light vision. The common octopus's large eyes allow it to discriminate between objects. The human retina apparently 'pre-processes' image information before it reaches the brain.



COMPARATIVE EYE ANATOMY

"We still don't even know all of the different cell types that are inside our eyeballs," says Metha. "I've spoken about photoreceptors, but those photoreceptors then connect to the next set of cells called bipolar cells. And there's a whole bunch of different sorts of bipolar cells that haven't been fully characterised – or we're probably kidding ourselves that we have."

The way our eyes process what's happening is also hard to understand. The retina – a thin layer of tissue that receives light – has the strange ability to pre-process images before information is passed on to the brain. Information that's not needed is discarded and only the useful information is kept.

"A colleague of mine once said, 'The retina is a piece of brain that sort of popped out to take a look,'" says Metha. "There are some tricks that we know it employs. For example, there are signals from some parts of the retina that do mathematics – subtract or add information to adjacent parts."

The fovea sits in a small depression on the retina, in a tiny space located in the macula, and it's packed with cone cells. Humans aren't the only creatures that have them; most other mammals don't, but fish, birds and reptiles have fovea. That means our eye for detail might be more similar in some ways to a fish's than to a dog's or a cat's.

Interestingly, the shape of the pupil might change the way the fovea, and fovea-like structures, see. Frogs don't have them, but they might have something else.

"It's unclear whether other organisms have similar concentrations of cone or rod cell types in different parts of their retina and whether that might align with the shape of their pupil or if it's completely random," says Bell.

"The name for that potential structured organisation is called the retinal streak. That's basically unknown for most animals."

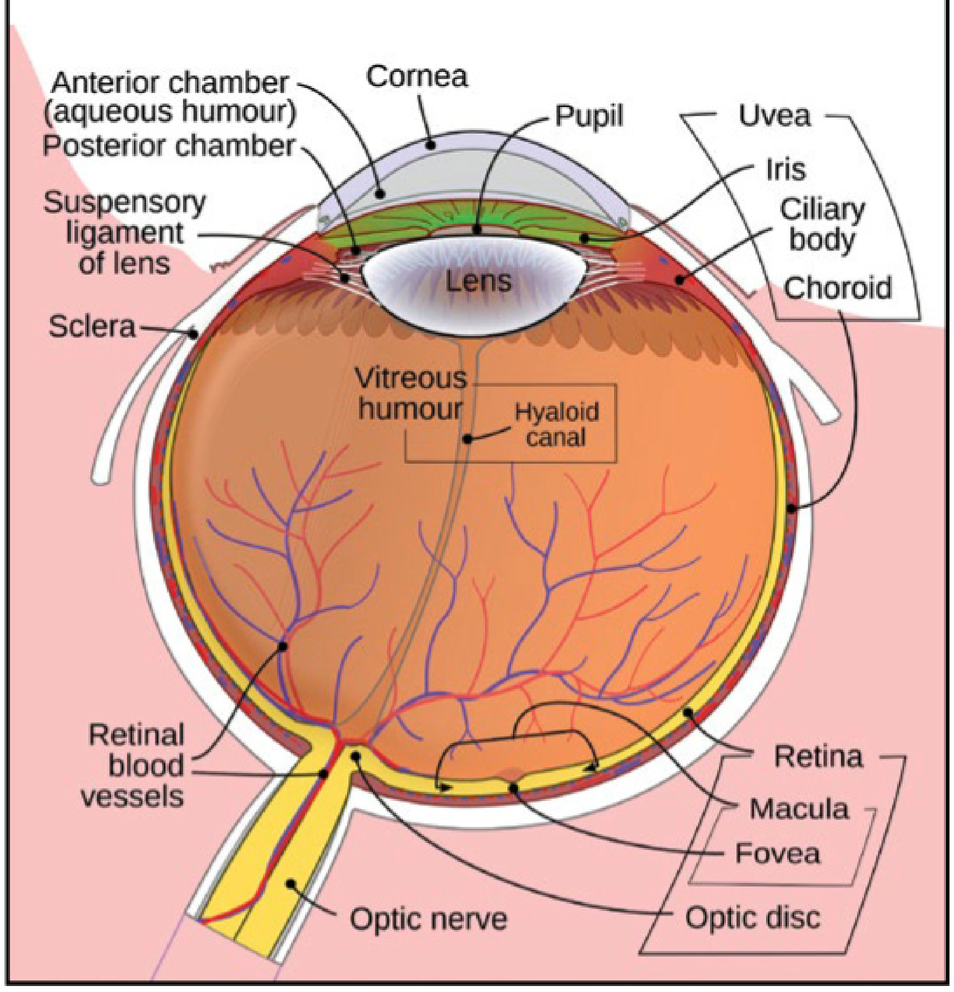
Owls, fish and algae with eyes

No eyes are bad, according to Metha; they just need to be fit for purpose. A fish that lives 500 metres below the surface doesn't need human eyes, and we definitely wouldn't want theirs.

Professor Justin Marshall, a sensory neurobiologist at the University of Queensland, has a slightly different opinion: "There's lots of eyes out there that are s**t."

TYANA AWADA

IN PLAIN SIGHT



Primitive eyes like those of the pelagic mollusc nautilus fit into this category. Nautilus have a pinhole eye, without a lens or cornea. This would result in extremely poor vision, but it seems to work for the shell-bound creature (*Read more about these ancient molluscs on page 82*).

“There’s not ‘better’, there’s a solution,” Marshall says. “If evolution has to deal with the physics of light, then you come up with these similar solutions. The reason that our eye and the eyes of cephalopods – octopus, squid, and cuttlefish – are really very similar is due to the physics of light and the need to copy the same solution.”

These ‘solutions’ are why the pinhole eye of the nautilus evolved into the sophisticated, vertebrate-like eye of the cephalopod invertebrates.

Marshall’s lab research investigates all sorts of weird and wonderful eyes – from mantis shrimp to octopus – everywhere from the top of the sea to the bottom. One particular oddity he talks about in his lectures is that owls and some deep-sea fish have the same eyes.

Unlike human eyeballs, which can move inside our eye sockets, owls have a tube-like structure that can only look straight ahead. These tube eyes help the owl see in low-light conditions – just as is the case with deep-sea fish like anglerfish.

Although they’re only distantly related, it’s likely that convergent evolution allowed their eyes to create a similar solution for a similar problem. It seems a little weird, but convergent evolution – evolution creating similar-looking and -acting structures in distantly related creatures – happens all the time.

What’s even weirder is a type of dinoflagellate called the warnowiids. These single-celled eukaryotes are usually considered to be algae. But they also seem to have ‘eyes’ – called ocelloids – that are also incredibly tube-like.

“You look at a single-celled animal and it contains an eye, and when you look at a cross section of this eye it’s just like an owl,” says Marshall.

“It appears that the single-celled animals (if you can call them animals) can subdivide the cell into usable units. They appear to have a structure that’s like the retina and they have a lens, so they have a focusing apparatus. They have a cornea.

“It’s really weird.”

Marshall and his colleague Professor Dan-Eric Nilsson wrote about this seeing single-celled creature in *Current Biology* in 2020.

“It has been claimed that warnowiids cannot have vision because they have no brain,” Nilsson and Marshall wrote.

“This is of course nonsense. The complex behaviour of many protists is based on processing of external information. But protists clearly have to use other means than neurons to process the information needed to perform behaviours.”

Of course, there’s still much that we don’t understand. There’s no conclusive evidence that ocelloids really are eyes, despite them looking and acting a lot like them. Considering how little we know about eyes generally, warnowiids and their weird little ocelloids are far down on our list of understanding.

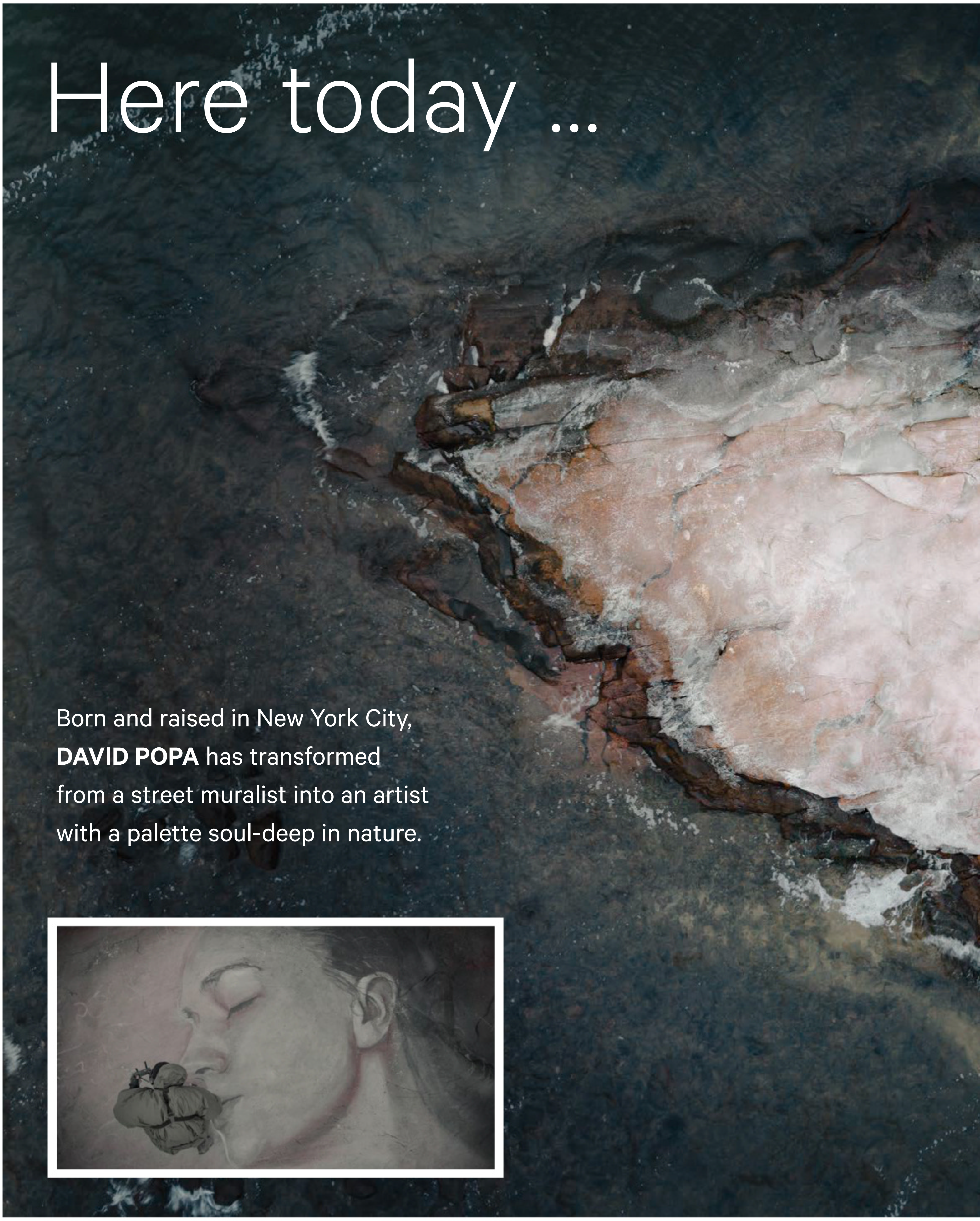
There are also a lot of results that seem to work in some animals but come undone in others. Back in 2015, a flashy paper published in *Science Advances* found that prey animals were more likely to have horizontal pupils, and predators were more likely to have vertical pupils.

This makes sense in owls, cats and goats, but starts to break down beyond the 214 vertebrate species the researchers looked at. If we bring it back to frogs, they have both vertical and horizontal pupil shapes.

“It doesn’t really make sense when you look outside of the species that they included, or even the types of animals that they included in their study,” says Bell. “It can be a good reminder that when we want to make these really big claims, it can be helpful to take a step back and look at a broader subset of animal diversity on the planet.” ◉

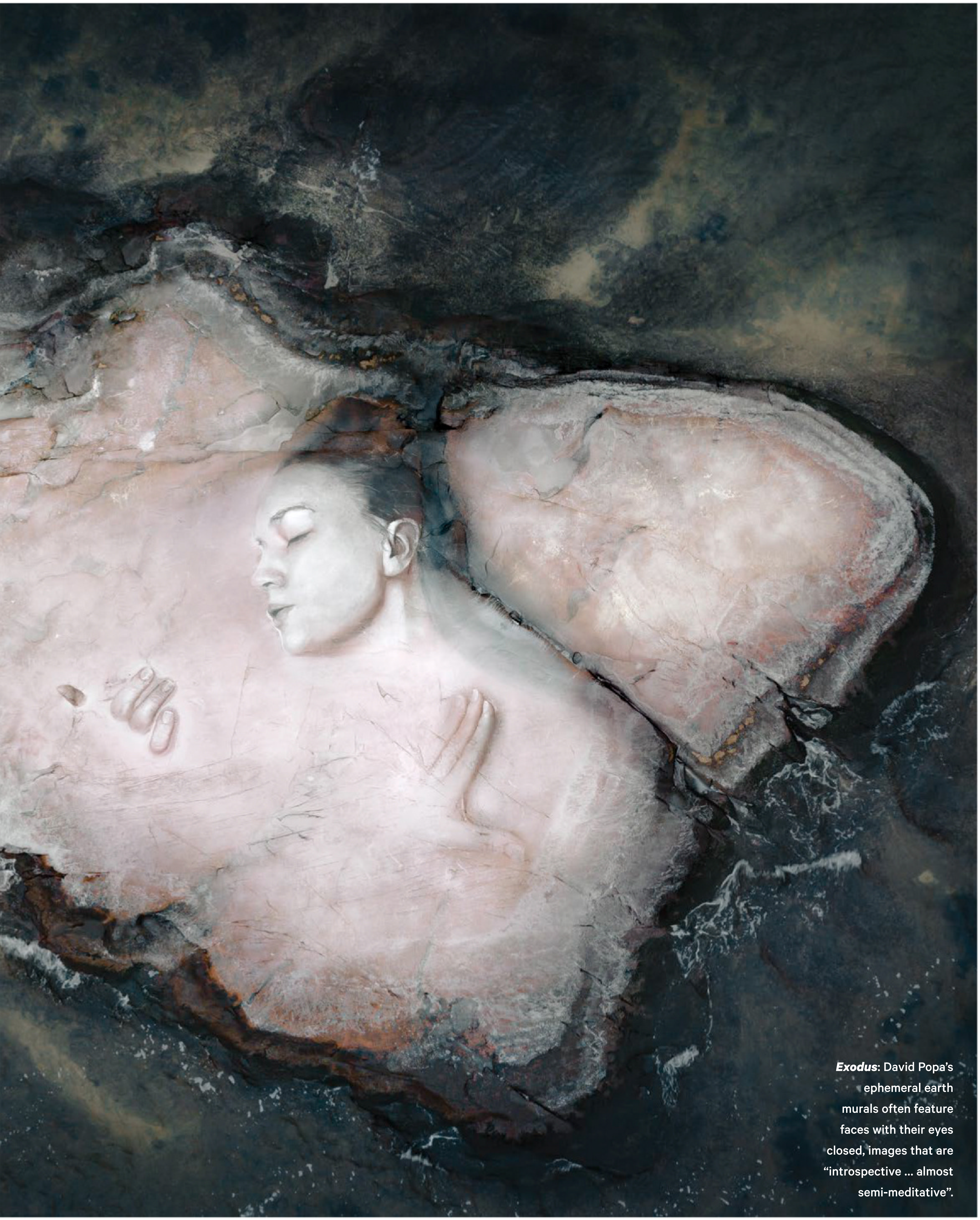
JACINTA BOWLER is a science journalist at *Cosmos*. Her last story for the magazine, on the SABRE project, appeared in Issue 94.

R.H. CASTILHOS, JORDI MARCH / WIKIMEDIA

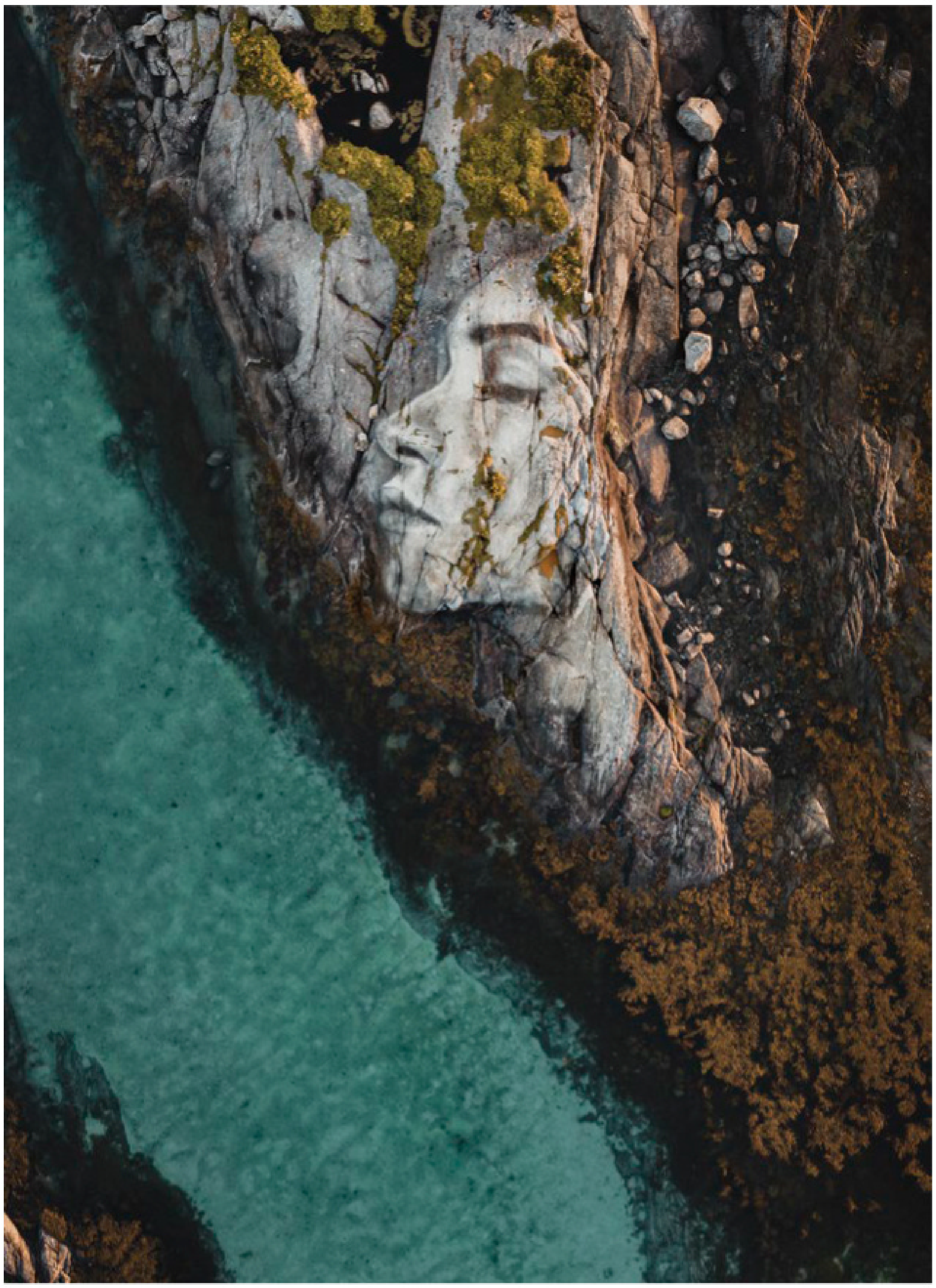


Here today ...

Born and raised in New York City, **DAVID POPA** has transformed from a street muralist into an artist with a palette soul-deep in nature.



Exodus: David Popa's ephemeral earth murals often feature faces with their eyes closed, images that are "introspective … almost semi-meditative".



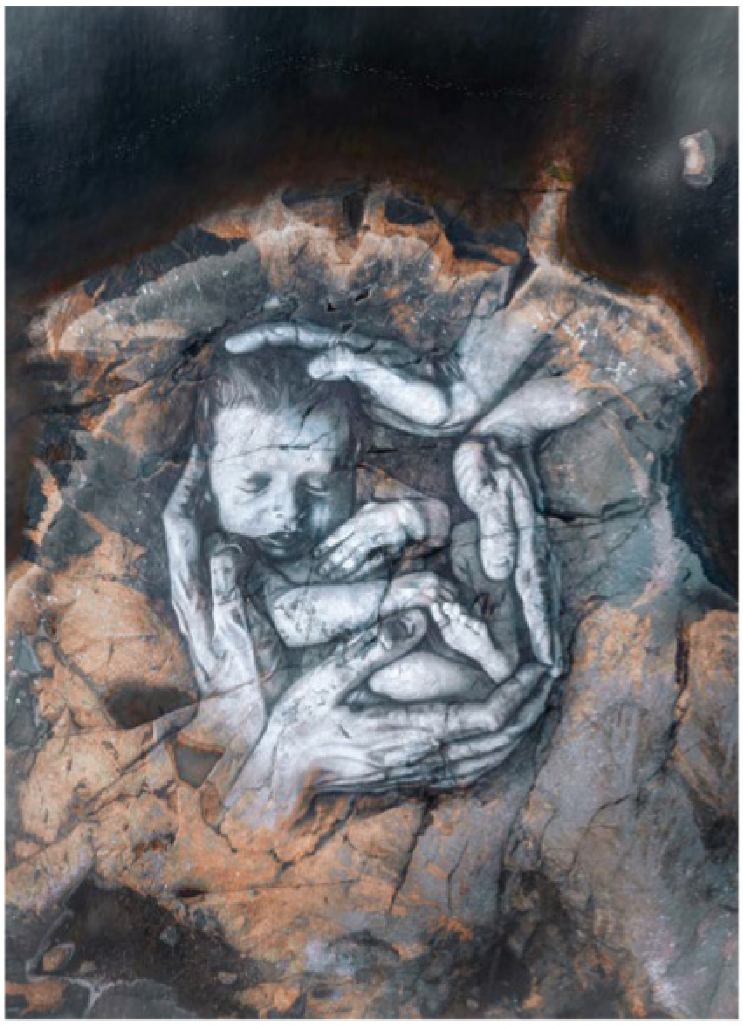
A woman's face emerges from a rocky archipelago in the Bergsøyan Islands off the Norwegian coast. Stone cracks and crevices form the contours of cheekbones, while land artist David Popa sculpts the forehead, nose and closed eyelids by spray painting in natural pigments mixed with water.

When viewed from above – in photos captured momentarily by drone – Popa's art seems to have uncovered something already foreshadowed by the landscape. But with no binding agents to hold the colours, his work is ephemeral, destined to be washed or swept away by the elements.

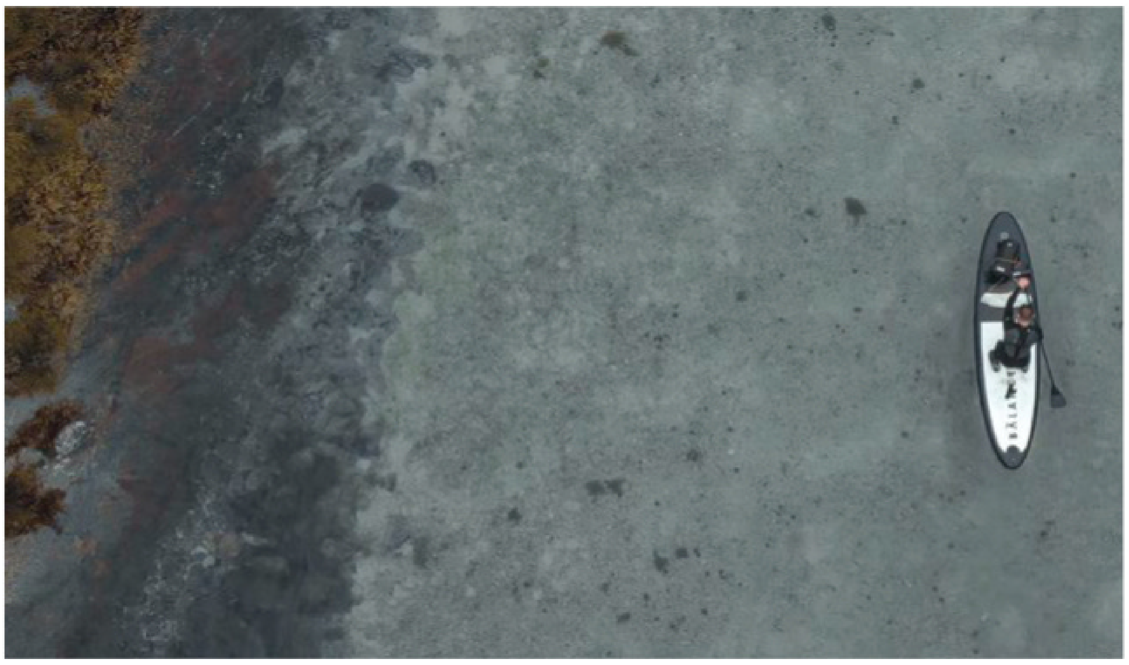
Popa is based in Finland. Over time, his work has transitioned from street art's urban setting and its toxic spray paints to large-scale earth murals drawn on rock, ice and soil using natural materials.

Each artwork, stretching to 10 or 20 metres, is designed to be viewed from a bird's perspective, yet painted at ground level using pigments created from the landscape.

Working at scale, Popa draws on street-art techniques. He takes a reference photo by drone, which he marks up using the computer program Procreate. The cracks and natural formations in the landscape mark the space like a grid overlay, which he uses to guide his work alongside intuition and "knowledge of where the dark and light goes".



Popa makes the final decision about which image to paint once he's on location. "I'm huddled, kind of under a rock, with a bunch of jackets and I'm on location … I feel like I'm trying to uncover something." While context plays a role in his choice – the anatomy of the face, the way a nose lines up with the edge – there's intuition too. "If I feel it impacting me, hitting me on a deeper emotional, even spiritual level, I'll be like, 'that's the piece, I'm moving in that direction'." (Top left: *Inceptus*. Left and opposite: *Born of Nature I* and *II*.)



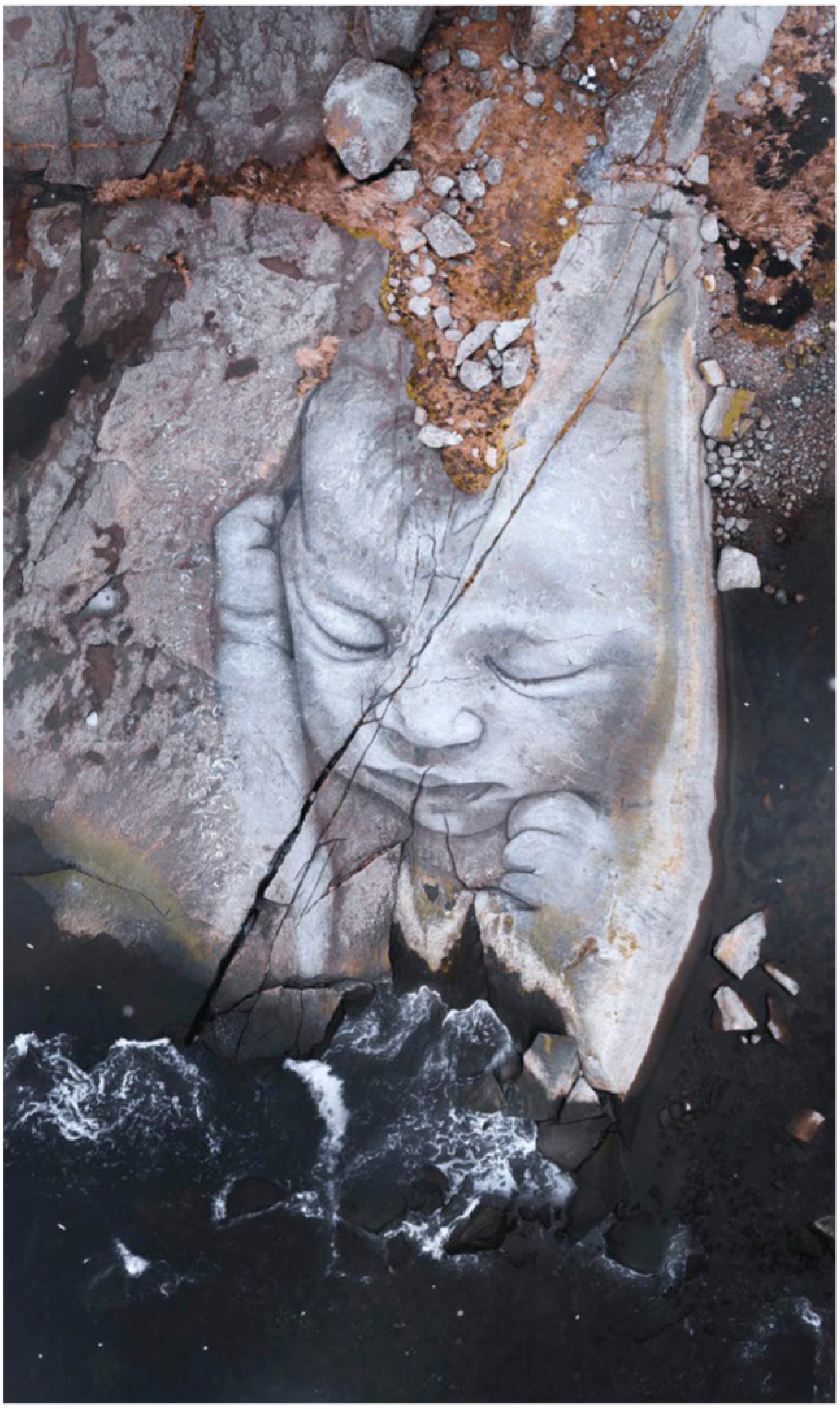
"Because I'm painting in areas with a lot of texture, it's actually incredibly intuitive and extremely fast," he says. "I can go up, snap photos with the drone, transfer it to my phone and get my reference – I'll have a sketch or something that I'm referencing – and based on the cracks, and based on the natural formations, that's guiding me in my proportions."

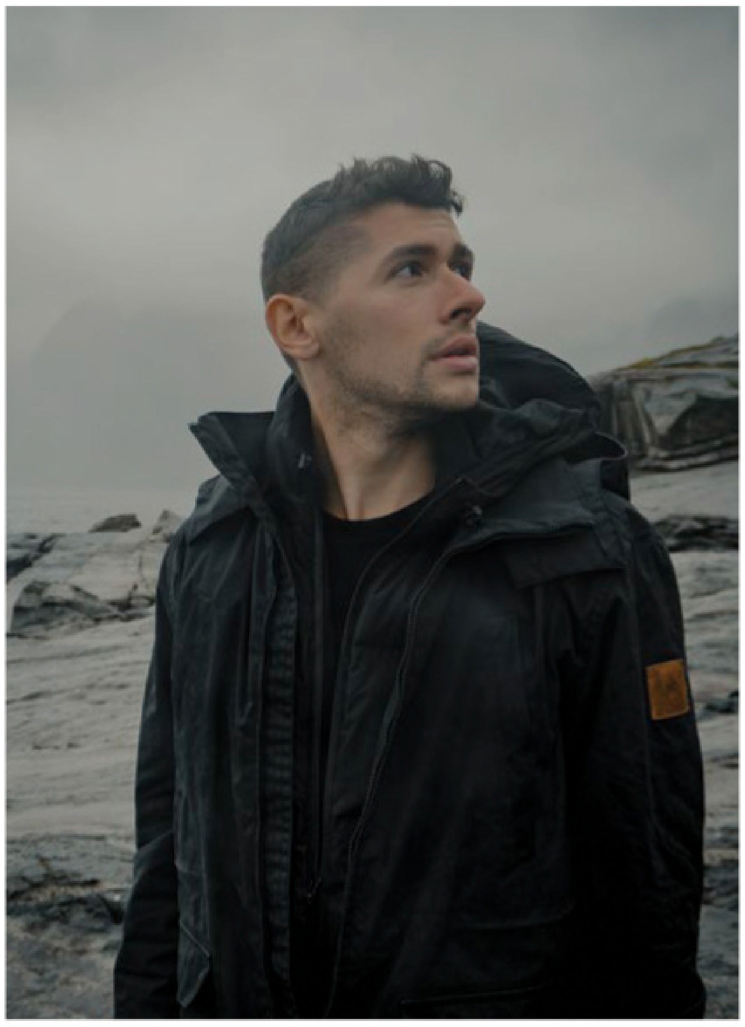
He loves the challenge of working within nature's constraints, timing effort between tides or in advance of forecast rain. For *Inceptus* (opposite, top), Popa had a 10-hour window of Nordic sunshine to work with before the rain set in. He'd barely finished at 2am or 3am, and what happened next was unexpected.

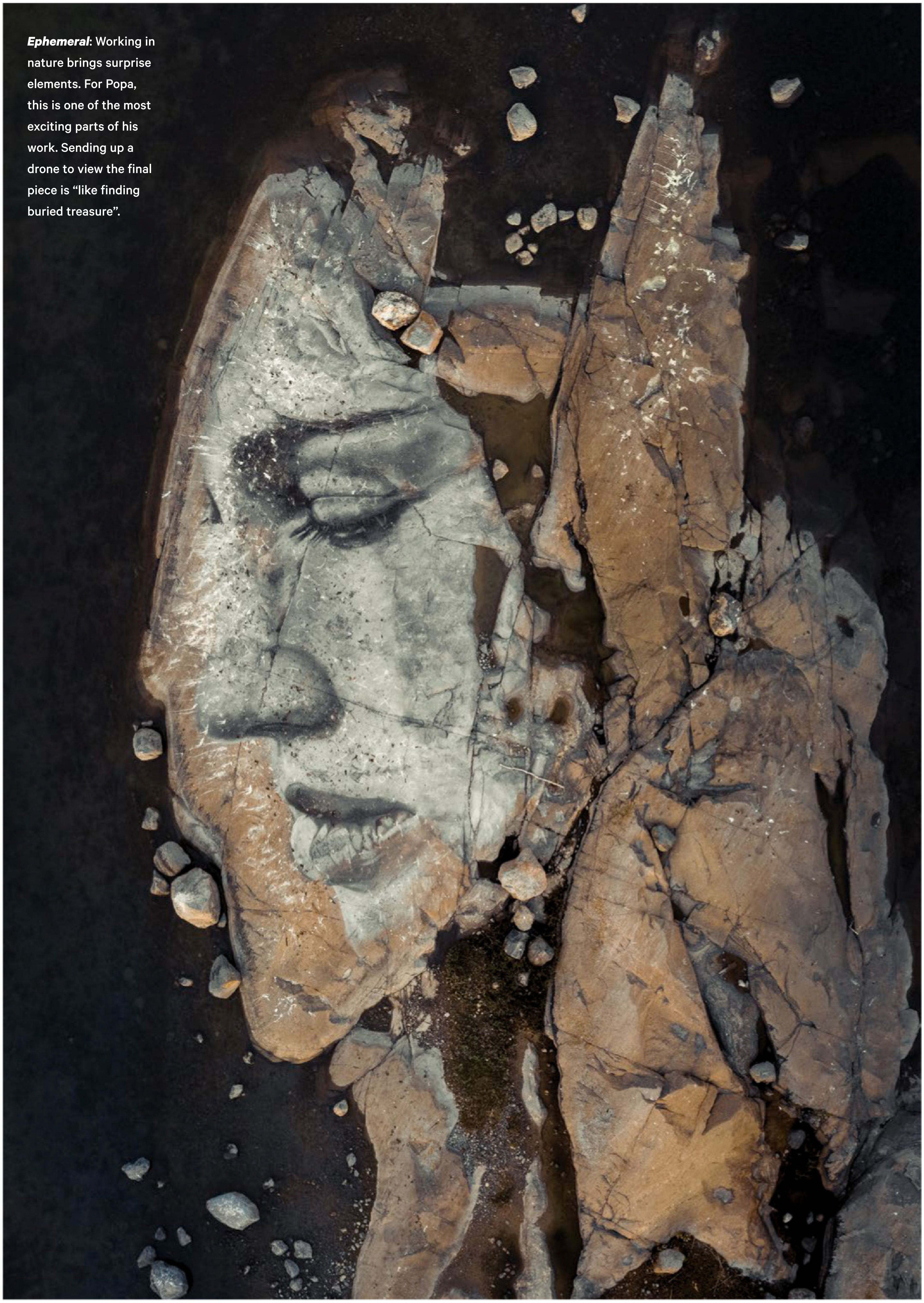
When sending up the drone to photograph the final image, "the tide went lower, and sort of this unreal thing happened where the rock basically looked like the neck and then the clavicle of the neck".

Like the receding tide, natural processes frequently bring a surprising and beautiful element to his work, Popa says. From faces that fracture as ice cracks, to the dynamic brush strokes of splattering seabird droppings, or skeletal remnants left after a work has nearly washed away.

For his *Fractured* series, painted on ice floes in southern Finland, Popa found through trial and error that a temperature of 0°C is perfect for painting on ice. Too cold and his marks froze over; too warm and the ice melted.

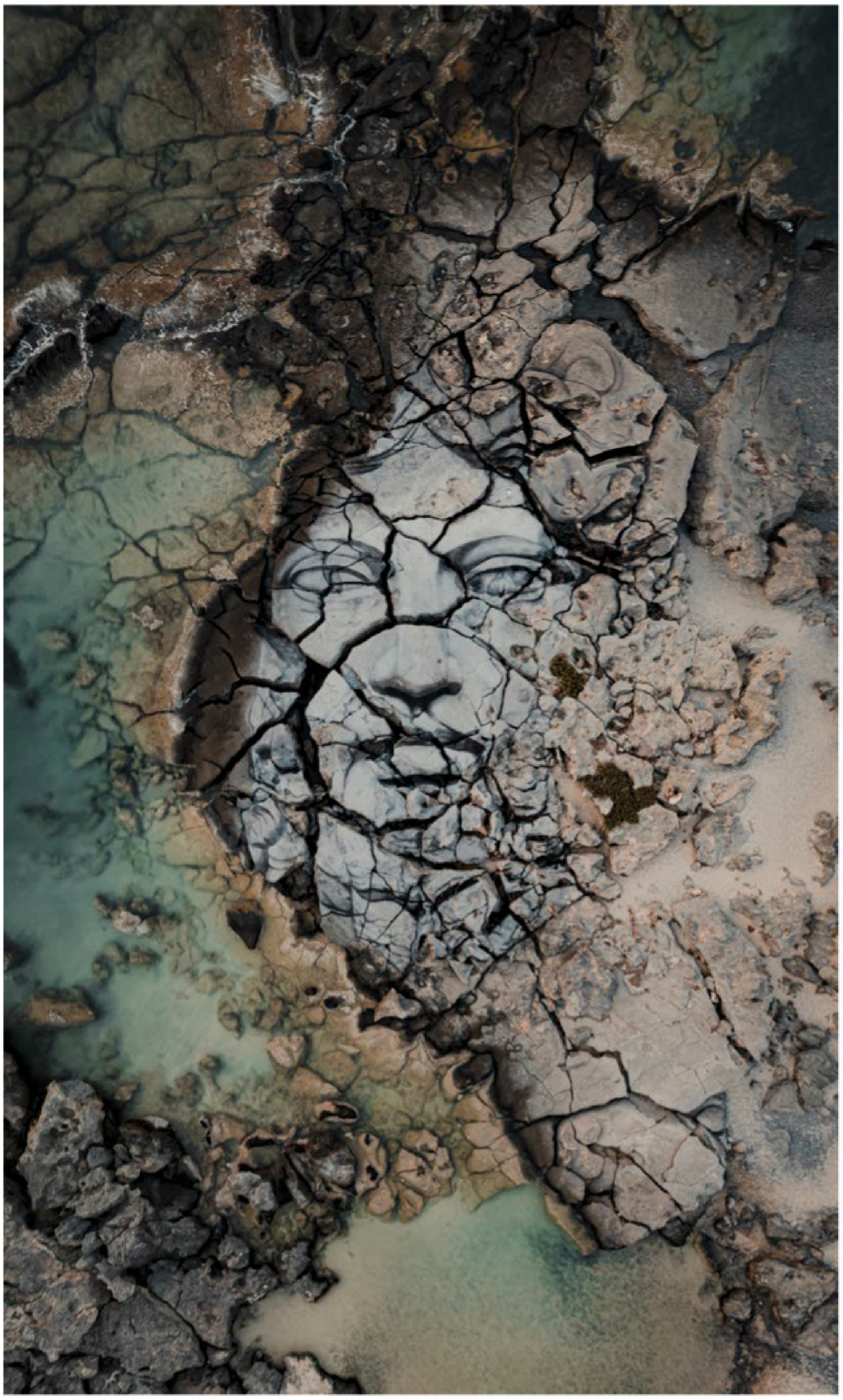






Ephemeral: Working in nature brings surprise elements. For Popa, this is one of the most exciting parts of his work. Sending up a drone to view the final piece is "like finding buried treasure".

Prometheus: "I love to be in nature," says Popa. "So much more than the urban context." He uses techniques from street art to paint at a large scale. The cracks and natural formations act as a reference, guiding the proportions.



There are other variables to consider too. For example, sunshine could change the temperature on the ice.

"If the stars align, I have to do it very fast… this charcoal will sink in deeper and deeper into the snow," Popa says. "And so it's basically going from dark, and it's just fading, it's going deeper, and it's just becoming lighter as the minutes go by."

The availability of natural, locally sourced materials for making pigments usually determines the colour palette, whether it's chalk from the Champagne region of France, or the deep earth tones produced by local quarries in Italy and Greece.

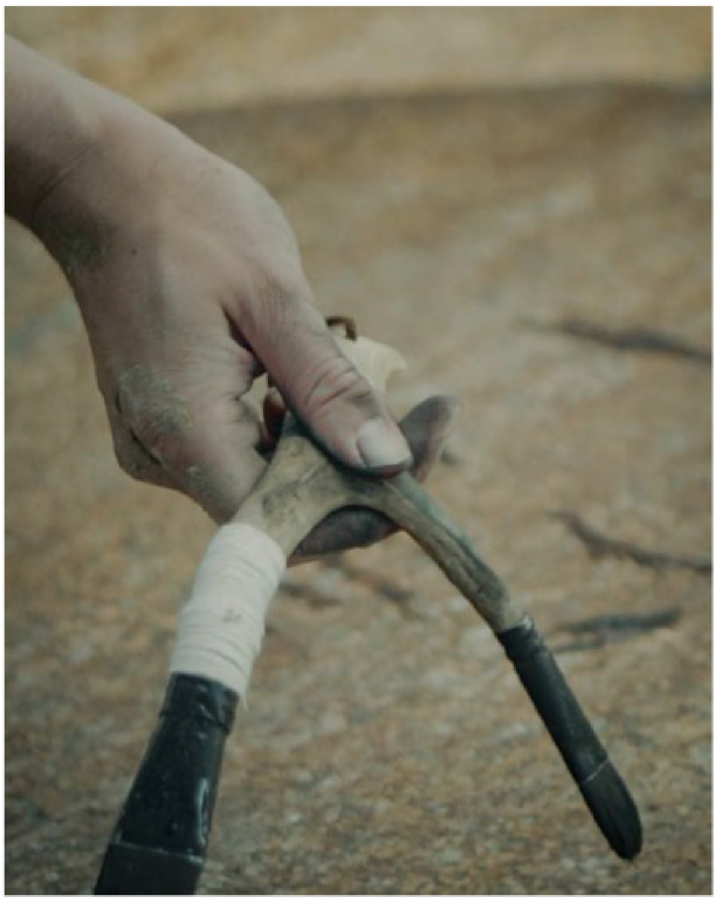
For a project on the grounds of a vineyard, Popa even used the gross lees that settle as wine ferments for colour, producing a painting of grapes rendered in deep purples, maroons and plums.

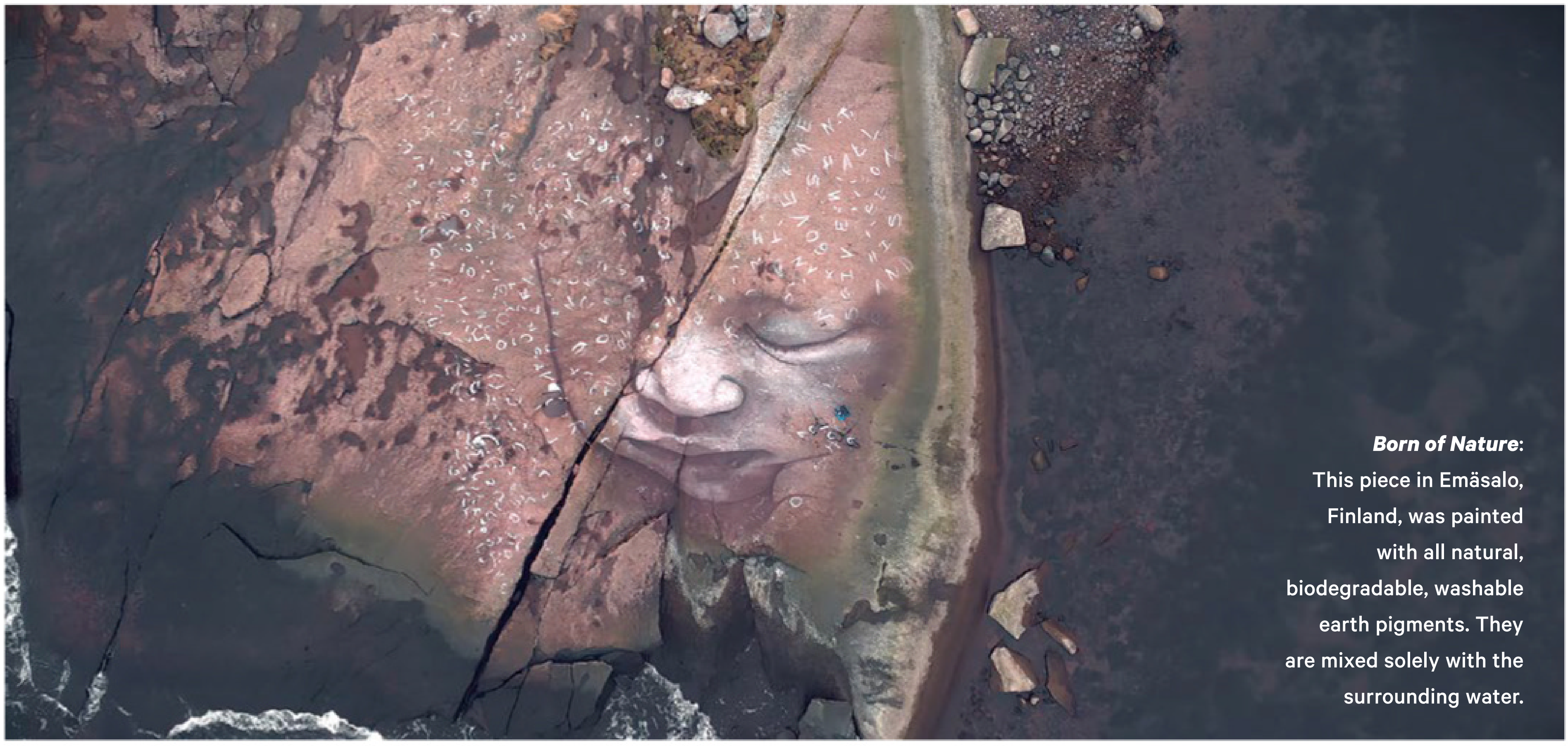
For the first work in *Fractured*, Popa made his own pigments from wood in Finland.

"That was my own charcoal that I made myself, placing these birch twigs and things into a tin can… basically putting it through this low-oxygen process, pulling it out and then grinding it down with the mortar and pestle."

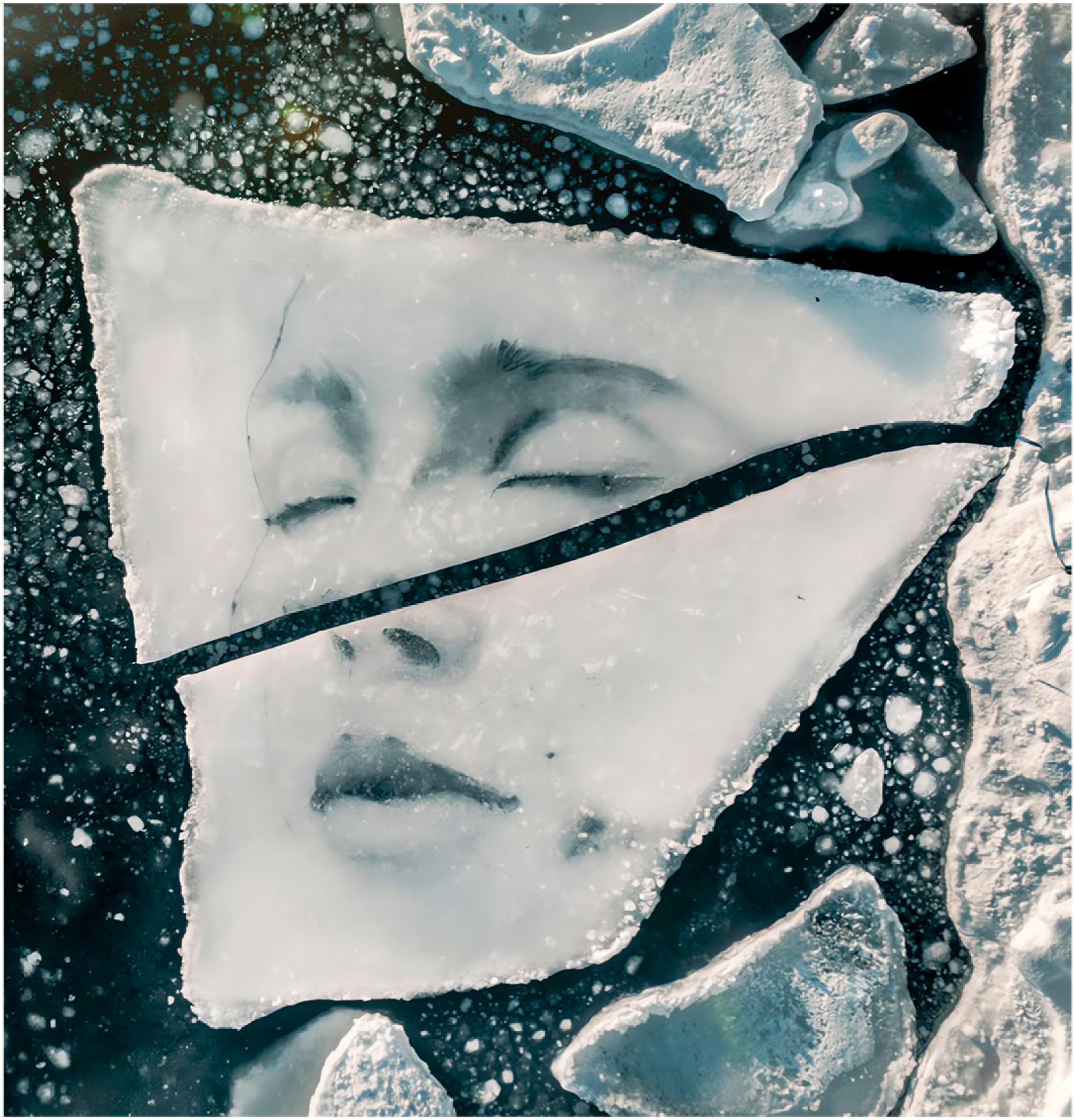
The lack of any binding agents means his works are transient: "Charcoal with water will wash away very quickly. Whereas something like iron oxides… some of these earth ochres will stain the rock for a longer period of time, but it will still wash away."

Natural pigments: Popa says while he loves the exploration of street art, he couldn't reconcile some aspects: "I love the medium of spray paint, but you have a big mask on, it's toxic."





Born of Nature: This piece in Emäsalo, Finland, was painted with all natural, biodegradable, washable earth pigments. They are mixed solely with the surrounding water.



While Popa is interested in ecology and the environment, his reasons for making these ephemeral earth murals are much broader. He aims to capture a kind of existential awe, describing it as akin to what a scientist might feel when looking through a telescope.

"You look at the vastness of the universe, and you're like, 'Who are we?' " he says. " 'What are we doing here?' There's these much larger, bigger questions and sort of the mystery in the miracles of life become really kind of present."

After the image is made, Popa will fly a drone to capture it in a series of photos, stitched together to reveal the whole image. The resulting limited-edition prints are released for sale.

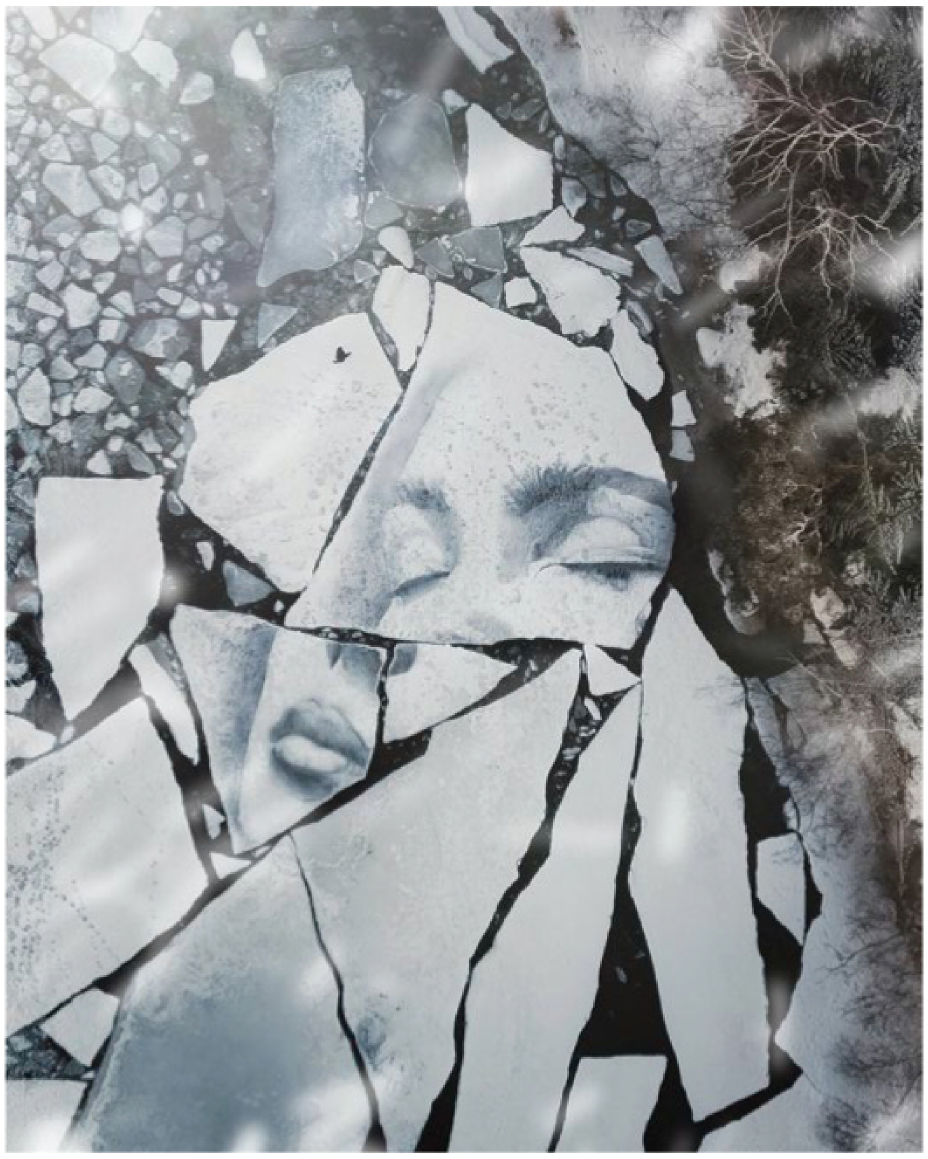
One of the most sought-after parts of his art are the non-fungible tokens, or NFTs, associated with the drone videos that show Popa adding the final touches to his work. As the drone lifts higher and higher it reveals the entire context of the artwork in the landscape.

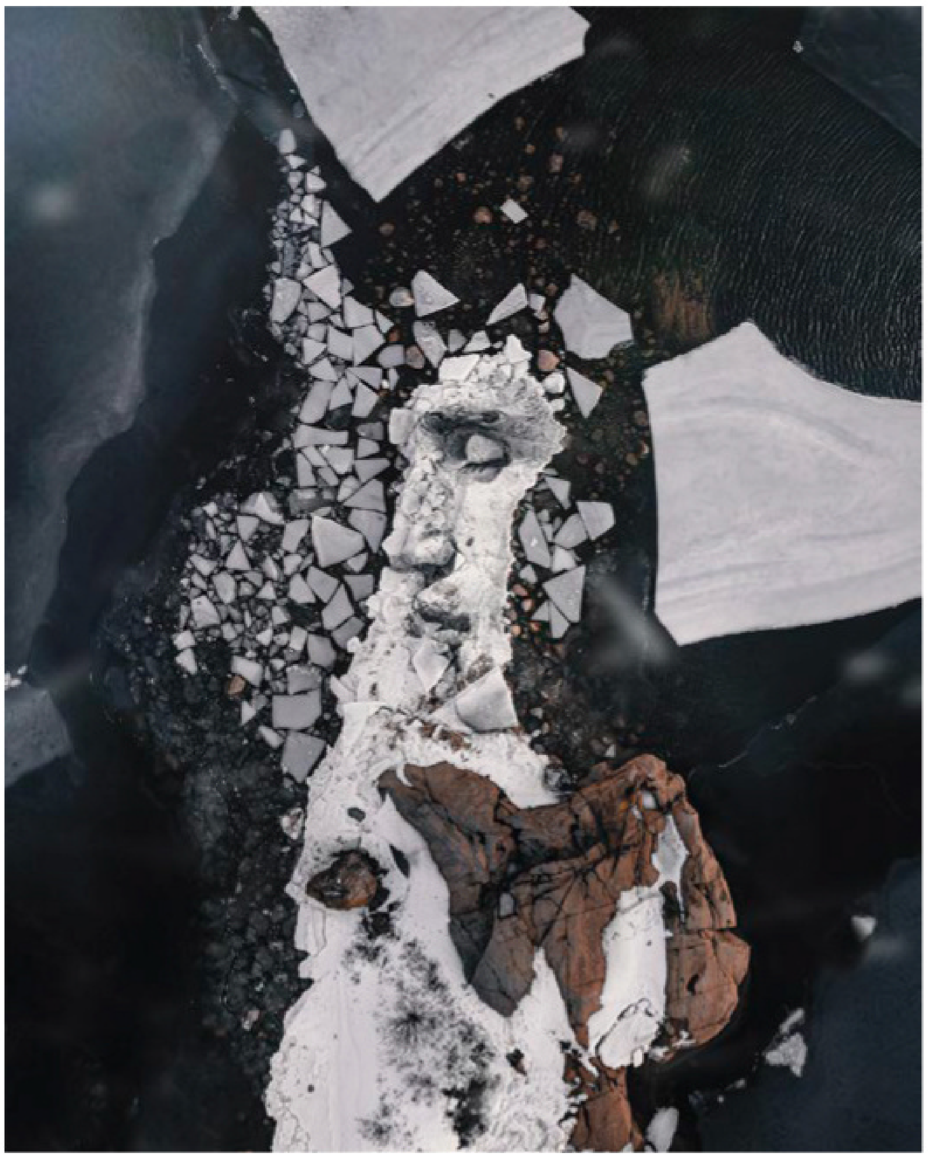
Having worked on so many faces and portraits, Popa says he is thinking about a new series based on uncovering fossils in the landscape, rendered at the locations where certain animals – woolly mammoths, dinosaurs – have become extinct.

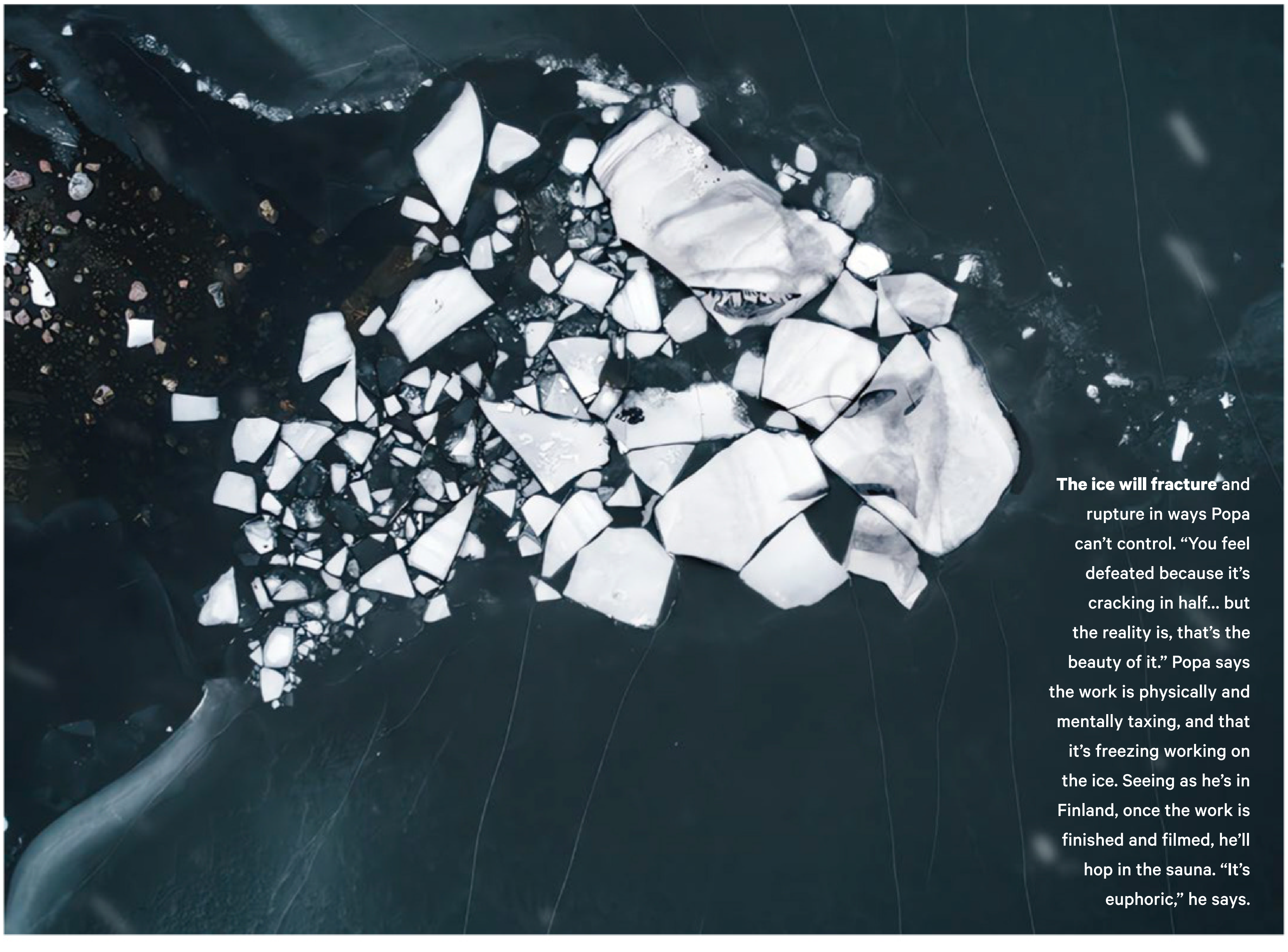
"The work has to do with this feeling of uncovering and unearthing," he says. – *Petra Stock*

To read more about Popa and see other works, visit www.davidpopaart.com

Fractured **NFT series**: Painting on ice floes is as equivocal as you'd imagine. Too cold and Popa's marks freeze over; too warm and the ice melts. "This is the day, it's zero degrees, it's perfect temperature ... you can't be making any mistakes, it's like drawing with pen."







The ice will fracture and rupture in ways Popa can't control. "You feel defeated because it's cracking in half… but the reality is, that's the beauty of it." Popa says the work is physically and mentally taxing, and that it's freezing working on the ice. Seeing as he's in Finland, once the work is finished and filmed, he'll hop in the sauna. "It's euphoric," he says.

GRINDING ON SCHEDULE

Teeth grinding: so far, so boring – right? But palaeontologist **Michael Archer** and dentist **Christopher Telford** agree that there's an intriguing evolutionary reason why it's so common, and explain why a psychologist's couch might offer more relief than a dentist's chair.

TAB1962 / GETTY IMAGES

Humans are a little out of the habit of using their teeth as weapons, but they understand a threat display when it appears. Part of our response to the stress of threat, say authors Archer and Telford, is ‘thegosis’ – grinding our teeth in order to sharpen them.

What are teeth for? Most will say "chewing". But consider this: you're walking through the bush, you step over a log and suddenly there is a snake rearing angrily, as if it's about to bite you. If it's too small to eat you, why is it threatening to bite you? The answer is because it's scared witless, terrified of you, and it's getting ready to defend itself as part of the instinctive survival response known as fight or flight, or the acute stress response. So what's the relationship between this sort of stress and our own teeth? The surprising answer is tooth-grinding.

Most dentists call tooth-gnashing or tooth-grinding 'bruxism', a term that doesn't, unfortunately, explain anything about the reason why it occurs. In contrast, the term 'thegosis', first published in 1970 by New Zealand dentist Ron Every, is used by aware dentists and zoologists for the same process that occurs in many animals, including humans. Thegosis is a Greek word that means to sharpen or whet – in this case teeth, beaks or other interacting hard parts. These parts are 'ground' against each other to sharpen their cutting edges for whatever purpose they need to serve, from eating to fighting.

Activities like eating and fighting dull the cutting edges of the teeth just as use dulls knives and scissors. Animals whose upper and lower teeth don't actually meet, such as sharks and crocodiles, replace their worn teeth by erupting new ones, just as surgeons replace their scalpel blades when they become dull.

Animals, including humans, whose upper and lower teeth or beaks contact each other can resharpen them by grinding one against the other in a very precise manner, just as a butcher sharpens a dull knife by pulling it back across a sharpening stone in the opposite direction to which the knife is to be used to cut.

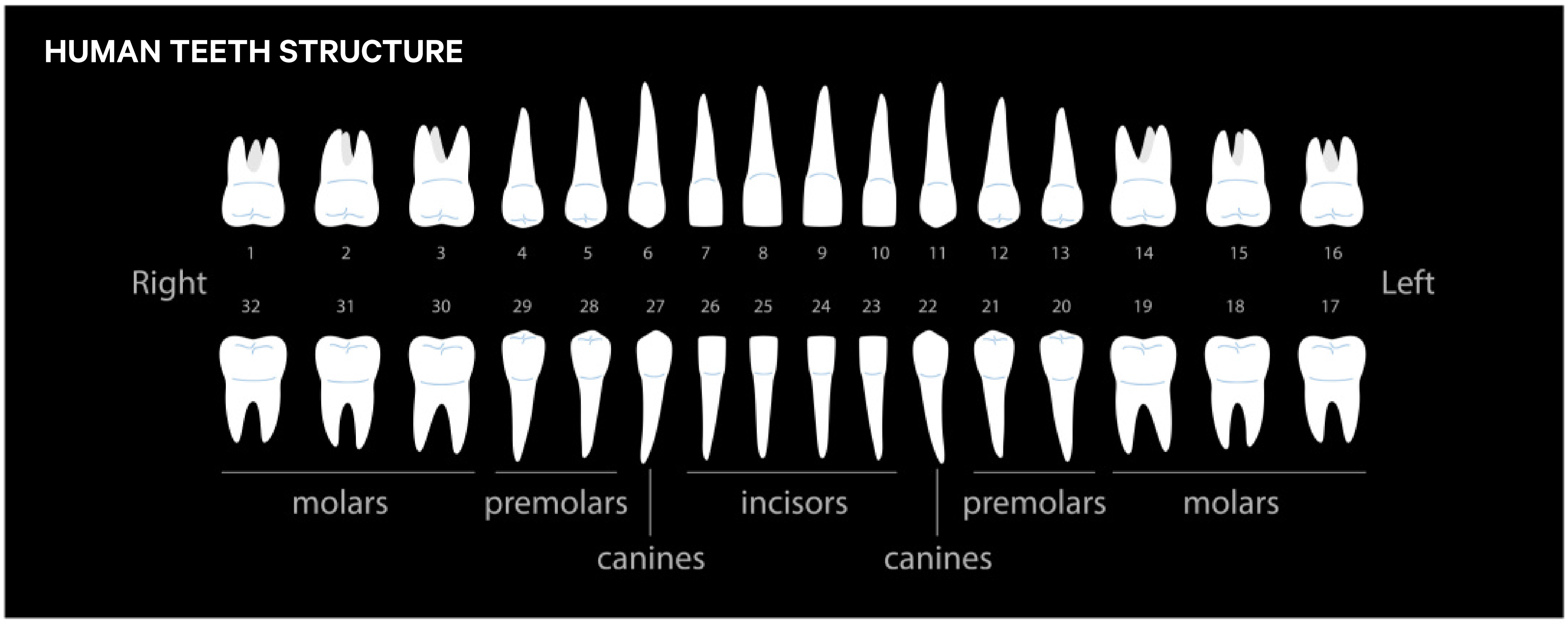
But teeth and beaks are not just used for food-processing; they're also used as weapons. We don't commonly think of our teeth this way because most of us have been socialised into not biting other people, no matter how mad we get. This training starts early with very young children, often called "ankle biters" until they've had this inclination brow-beaten out of them.

The concept of thegosis relates tooth-sharpening to the fight or flight instinct in all animals. In mammals it results in tooth-sharpening of the anterior teeth, thus preparing them for use as a weapon as well as for cutting up food.

In humans our incisors and canines are our primary biological weapons. Our primate cousins (apes, monkeys and their relatives) have relatively longer canines than us, which they use as their primary biological weapon. Because humans have, over the last eight million years, evolved shorter faces, without muzzles, in which long canines would be difficult to use, we've developed a relatively shorter horizontally thegosed canine that works with our sharpened incisors to form an equally formidable dental weapon.

Most of us find it difficult to accept the idea that our front teeth are part of a weapon system and that grinding – or thegosing – them is an essential means to keep them sharp. For this to work, the lower teeth are ground against the upper teeth in a forwards and sideways direction, more or less the opposite of the direction in which we use our teeth to cut or bite. It's the same strategy we described the butcher using.

Thegosis also resharpens the rest of our dentition (i.e., premolars and molars) in order to maintain its ability to turn food into small bits. Thegosis is normally the most forceful mechanical stress that our teeth experience. Teeth barely touch while chewing even the toughest foods. In contrast, during thegosis,



HAKULE / GETTY IMAGES

Most threat displays are instinctive – part of the survival response known as fight or flight. Thegosing – grinding – teeth has a distinctively hostile look and sound.

ROLIWANSYAH ANANTA / EYEEM / GETTY IMAGES

> When tooth blades are dulled by use during the processing of food, thegosis will occur to once again resharpen those blades.

the teeth meet and move against each other forcefully with no food in between them.

When this is happening, the lower jaw is being clenched against the upper jaw and then pulled sideways or obliquely by our transversely orientated lateral pterygoid muscles, which link the inside of each jaw to the base of the skull. These powerful muscles operate in a different direction to our more vertically orientated primary chewing muscles, the masseter (or cheek muscle) and the temporalis (or temporal muscle).

When thegosis of teeth occurs, it leaves shiny facets, the edges of which have sharp margins that serve as blades to help cut food into those smaller bits. The blades of the upper teeth work against the blades of the lower teeth much like an army of miniature scissors. In carnivores, these blades are primarily orientated in a vertical posture.

In herbivores and omnivores (like us), the shearing blades are primarily orientated and work in a horizontal manner. As the lower jaw moves sideways, opposing blades of enamel segment food items into small pieces in preparation for digestion. However, the blades in all of these teeth, whether they work in a vertical or horizontal manner, need to be regularly sharpened by thegosis to offset the dulling effect of cutting food items.

Microscopic examination of these tooth/tooth thegotic facets reveals fine parallel striations that are unlike the deeper, more irregular gouges produced by abrasion from food.

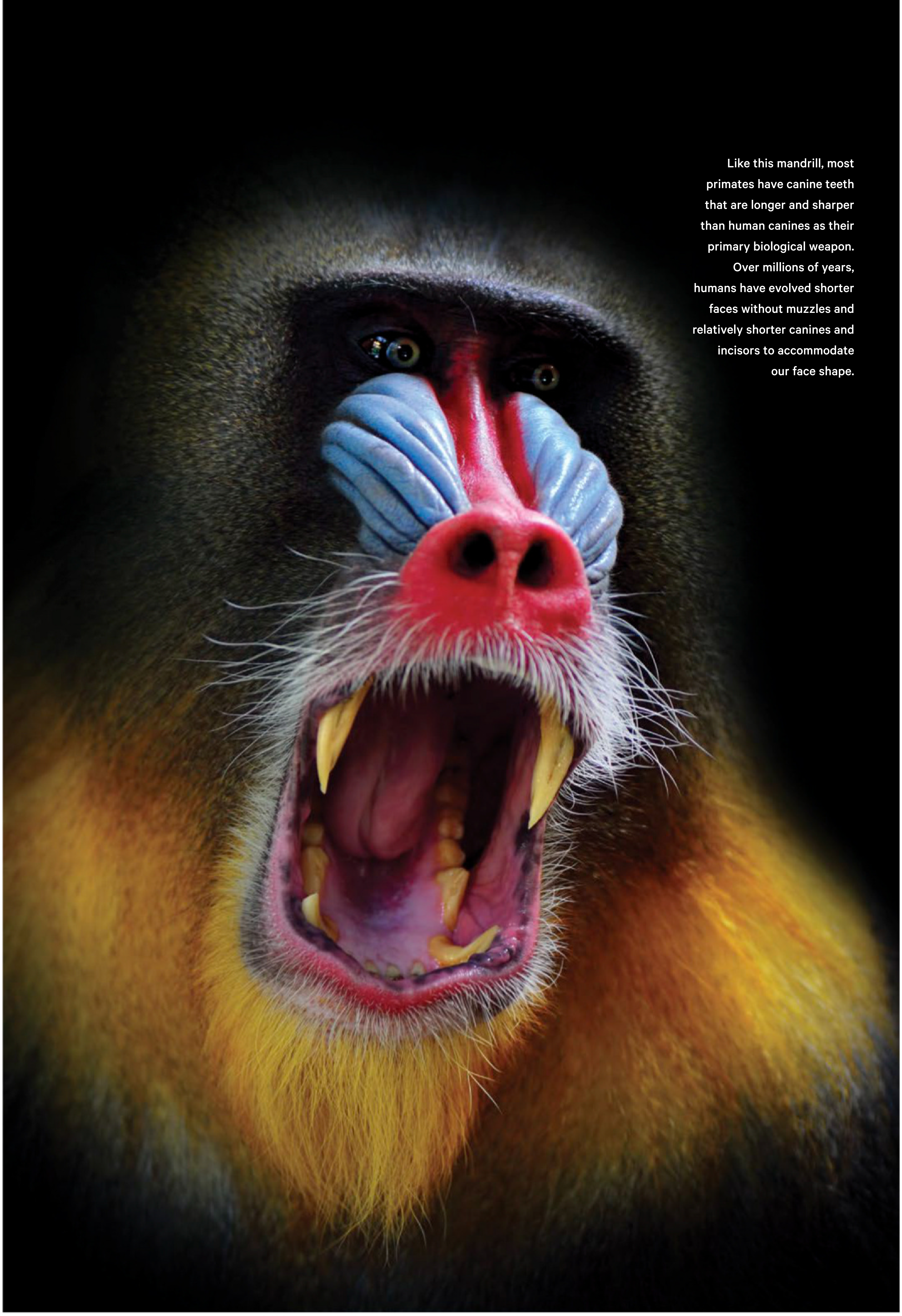
A similar situation can be seen in some luggage carousels at airports. In places where metal is rubbing on metal, shiny surfaces with fine microstriations are produced (like thegotic facets), while the rest of the carousel becomes covered in coarse irregular scratches from suitcases (like food abrasion on teeth) with no subsequent polishing from overlapping steel.

When tooth blades are dulled by use during the processing of food, thegosis will occur to once again resharpen those blades. Scissors don’t become sharper with use, knives don’t become sharper through cutting, and teeth don’t become sharper by processing food.

It is interesting to note that before our own cheekteeth are thegosed, or sharpened, when they are newly erupted, they lack blades that can cut tough food. As we age, we regularly thegose these teeth, which is why they begin to develop sharp blades that increase their ability to process food.

Even our incisors and short canines over time become much sharper and more efficient at cutting than they were when they first erupted, thanks to the cycles of wear from use followed by thegotic sharpening.

The sound of teeth sharpening other teeth is a bit like the shrieking sound of fingernails being



Like this mandrill, most primates have canine teeth that are longer and sharper than human canines as their primary biological weapon. Over millions of years, humans have evolved shorter faces without muzzles and relatively shorter canines and incisors to accommodate our face shape.

FREDER / GETTY IMAGES

> We humans have been taught to suppress the instinct to use tooth-grinding as an immediate response to perceived threats.

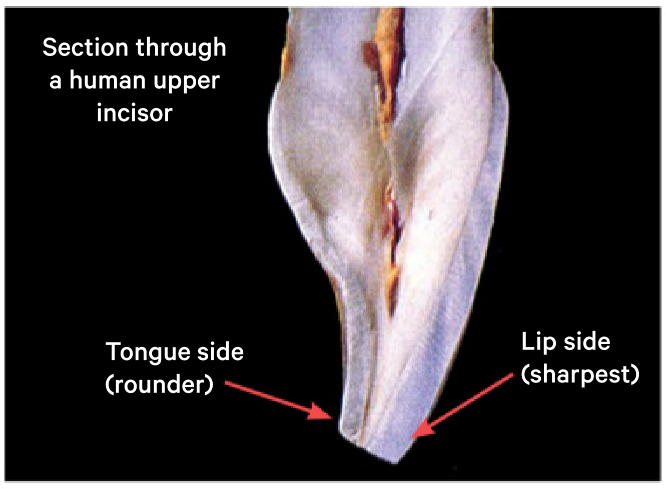
scraped across a blackboard. To someone listening to that ‘graunching’ sound coming from their child or partner, it can be highly disturbing – because instinctually we worry that the sound of teeth being sharpened means that someone or something is preparing or threatening to launch an attack.

Psychological stress, or anxiety, is a perception of threat. The more stress we are under during the day, the more intensely we will thegose our teeth. However, we humans have been taught to suppress the instinct to use tooth-grinding as an immediate response to perceived threats. Our brain does that suppression, but when it is resting during deep sleep, out comes the instinct and thegosis begins.

However, if a threatening or frightening confrontation is too intense, we may spontaneously thegose even while fully awake. When this happens, your mouth will distort into a grimace, with the upper lip on one side raised to display and visually warn that your teeth are offset in the process of being sharpened, and your eyes will partly close to avoid damage during the anticipated battle. These visual signals, combined with the sounds of teeth being ground and growling instinctually made with the voice, will make your response unmistakably threatening to an aggressor.

There’s much we humans need to understand about the natural behaviour of other animals that has evolved to reduce unnecessary battles. When dogs lift their lips to show their teeth and growl, the sounds they make in their throats mimic the sounds of tooth-grinding and add to the threat perceived by whatever they are growling at. We understand the significance of those behaviours, and back away. This in turn reduces the inclination of the dog to continue to threaten, which reduces the likelihood of an attack.

BITING ARGUMENT



COURTESY OF R.G. EVERY

If someone is feeling severely stressed, excessive thegosing can result in headaches, damage to parts of the face, head and neck, and to sensitive or even broken teeth. The solution to these problems is finding ways to reduce that person’s level of stress – it can’t be ‘fixed’ simply by manipulating the teeth. Even putting an expensive splint or plastic mouth guard in the mouth, as many dentists advise, will not fix the cause of the problem, although it may temporarily limit the amount of dental damage that occurs.

To really fix the problem, we need to find ways to reduce the stress levels that are the actual cause of the problem of excessive tooth-grinding. If the source of the stress can’t be removed, then yoga, meditation or the assistance of a psychologist can help to lower those stress levels.

Dentists have an important role, not yet widely recognised within the profession, to understand and explain the importance of thegosis to their patients. If their patients are presenting with problems associated with excessive tooth-grinding, they should be told that while tooth-grinding is necessary and normal, it can sometimes lead to problems if associated psychological stress levels have become too high. For some patients, simply explaining the relationship between stress and excessive tooth-grinding is sufficient to significantly reduce their anxiety levels and their associated symptoms.

It’s Medicine 101 to establish an accurate diagnosis with its cause before treating. It’s the dentist’s duty to make a causal diagnosis of the patient’s symptoms and, if appropriate, to refer severely stressed individuals to a psychologist, who may be the best qualified physician to ‘fix’ the problem. The provision of a plastic dental splint, which is recommended by many dentists, is a very expensive ‘aspirin’ that treats symptoms only.

The relatively new science of thegotics is a fascinating arena and one that is important for all of us to understand. Recognising our biological instinct to use thegosis to respond to an aggressor could well help us to minimise the severity of interpersonal battles and may even help us to better manage more dangerous scaled-up risks of international warfare. ◉

PROFESSOR MICHAEL ARCHER heads the vertebrate palaeontology lab in the Earth and Sustainability Science Research Centre at UNSW, Sydney.
DR CHRISTOPHER TELFORD, a practicing thegotician with a genetics background, runs a dental practice in Macquarie Street, Sydney.

Critical opportunity

Australia has a shot at supplying the rare minerals needed to drive a renewable-energy world, explains **JAMIE SEIDEL**. But can we mine them in a climate-conscious way?

They're not called critical minerals for nothing. They're irreplaceable. Without them, much of the technology our modern lives are built on can't work. And their supply isn't always guaranteed.

We need huge amounts of specialist minerals to electrify the world's economies, build battery farms and assemble renewable energy turbines. Not to mention their demand in everyday and defence gadgets.

That's why regional Australia is being scoured by foot and by satellite like never before. It's already the world's largest supplier of nickel, rutile, tantalum and zircon. It's also in the top five for cobalt, lithium, copper, antimony, niobium and vanadium. But we need much, much more of these – and others.

Australia has the potential to meet much of this need, says business management consultancy head Michael Huggins. And that's becoming increasingly viable as industries the world over begin to recognise the value of reliability and sustainability over cut-price deals.

The result could be the creation of about 52,000 jobs – mostly in regional areas says Huggins, the Australia and New Zealand director of Partners in Performance.

"As Australia positions itself in becoming the critical minerals powerhouse supporting clean energy technologies, the growth and expansion of downstream processing is expected to be phenomenal," Huggins says. "Apart from boosting the economy, it will breed a new generation of high-skill, high-tech jobs."

Now it's a matter of delivering on this promise in a timely manner, says Associate Professor Mohan Yellishetty, a resources engineering researcher at Monash University. "But to date, we are not making the most of this opportunity," he argues.

"Many of these vital minerals end up on the pile of discarded tailings. The question is, why are we not extracting them or re-mining them? Compared to other major critical mineral suppliers such as China, we are lagging behind."

Regional relevance

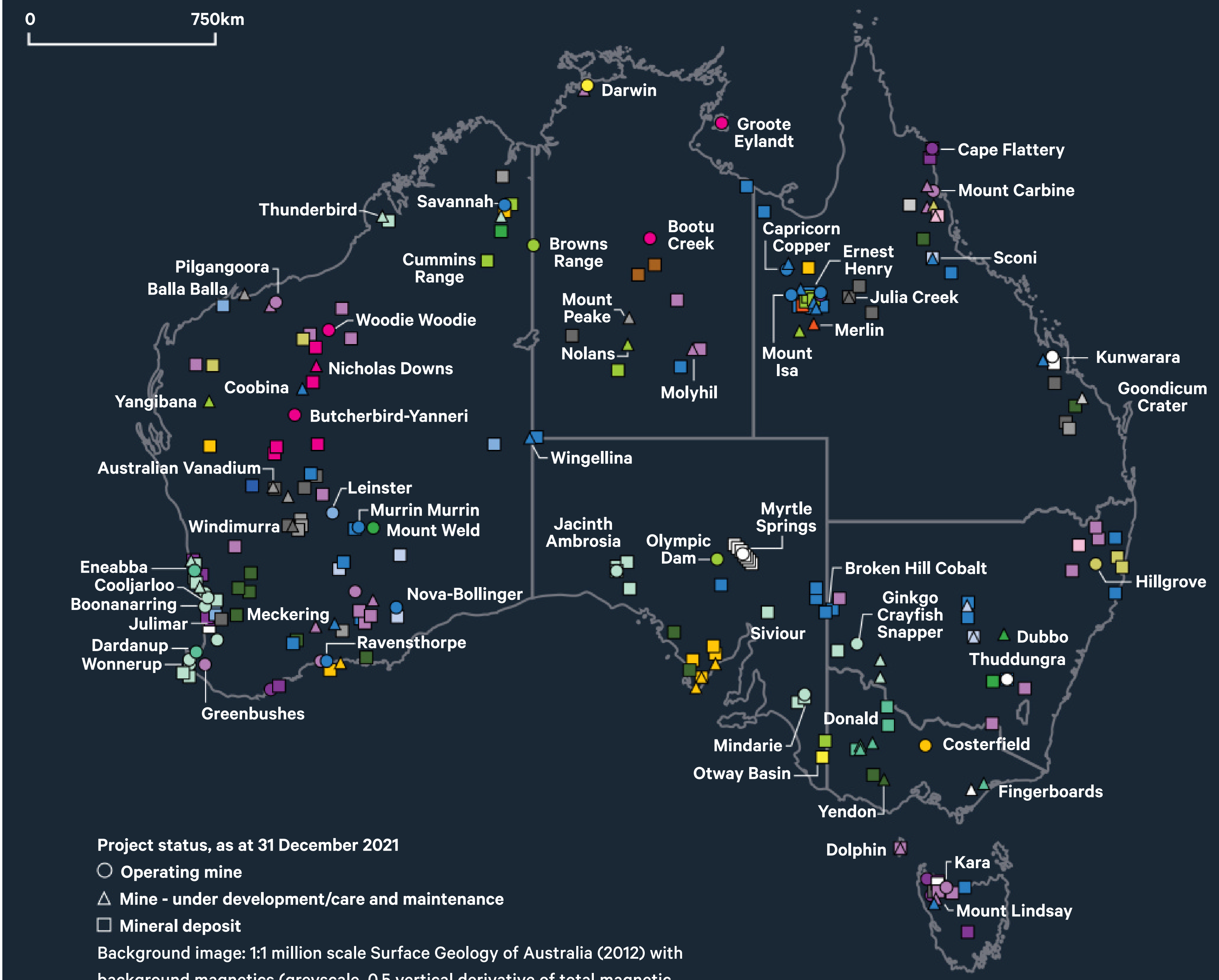
The importance of copper to electric components is well known. And lithium has become a household name as small but powerful batteries become ubiquitous. Then there are many more equally critical for modern technologies – like rutile, tantalum, niobium and vanadium.

POSNOV / GETTY IMAGES

A mineral-sands mining site near Busselton, WA.

Greenlight PROJECT
SUPPORTED BY THE WALKLEY FOUNDATION AND META

AUSTRALIAN CRITICAL MINERALS AT OPERATING MINES AND MAJOR DEPOSITS



Project status, as at 31 December 2021
○ Operating mine
△ Mine - under development/care and maintenance
☐ Mineral deposit
Background image: 1:1 million scale Surface Geology of Australia (2012) with background magnetics (greyscale, 0.5 vertical derivative of total magnetic intensity). For clarity, the map does not show all mineral deposits. Those depicted have been selected on the basis of size and significance.

COMMODITY TYPE

- ● Aluminium (HPA)
- ● Antimony
- ● Bismuth, +/- Cobalt +/- Indium
- ● Chromium, +/- Cobalt +/- PGE
- ● Cobalt
- ● Platinum Group Elements (PGE) +/- Cobalt
- ● Scandium, +/- Cobalt +/- PGE
- ● Graphite
- ● Helium
- ● Indium
- ● Lithium, +/- Tantalum +/- Niobium
- ● Magnesium
- ● Manganese ore
- ● Heavy Mineral Sands (HMS) - Titanium, Zirconium
- ● HMS - Titanium, Zirconium, REE
- ● Rare Earth Elements (REE)
- ● REE, Zirconium, Niobium, +/- Hafnium, Lithium, Tantalum, Gallium
- ● Rhenium
- ● Silicon
- ● Tungsten
- ● Titanium
- ● Titanium, Vanadium
- ● Vanadium

That's why the federal government's 2022 Critical Minerals Strategy in April granted a $1.25 billion loan to expand a facility in Western Australia.

It's Australia's first rare earth refinery, run by Iluka Resources at Eneabba, about 300 kilometres north of Perth. It will produce praseodymium, dysprosium, neodymium and terbium – all of which are used in small but powerful magnets.

Such magnets are a critical component of lightweight electric motors and generators, which represent the heart of the technological battle against climate change.

Similar projects seeking approval include a Hastings Technology Metals rare earths project at Yangibana, north-east of Carnarvon in WA (slated to begin by the end of 2023). Australian Vanadium wants to develop a site near Meekatharra, about 740 kilometres north-east of Perth. And Albermarle is building a lithium hydroxide processing facility at the Kemerton Industrial Park near Bunbury, WA.

Kalgoorlie is also becoming a focus of activity. Lynas Rare Earths has begun building a processing facility there (again expected to begin operations next year). And the historic mining town is the subject of a $119.6 million federal government Modern Manufacturing Initiatives feasibility study into becoming a battery cathode refinery hub.

Digging deep

The Australian Government has categorised 26 minerals as critical to our economic and technological future. "Australia has many of the elements the world needs to make advanced technology like smartphones, computers, solar panels, batteries and electric vehicles. We're already a world-leading resource exporter and supply many countries with high quality, ethically sourced minerals using environmentally sustainable practices," boasts the Department of Industry, Science and Resources.

But other key sources of supply – in Africa, Asia and South America – are struggling against internal unrest, corruption, and deteriorating public infrastructure.

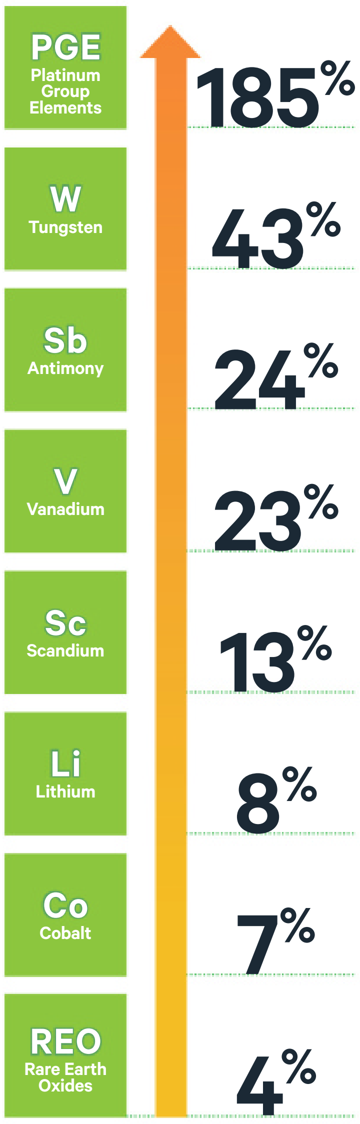
"In a time of huge geopolitical uncertainty, securing these minerals has become an ever more challenging issue. Soaring demand has led to price volatility, commercial risks, geopolitical manoeuvring and disruptions to supply," explains Yellishetty.

Because of their scarcity, such minerals have also become tools in international power politics – such as when China disrupted Japan's high-tech industries during a 2010 dispute.

"If we get this right, Australia could play a major role in stabilising the markets for several critical mineral supply chains such as rare earth elements, lithium and cobalt," Yellishetty says.

AUSTRALIAN CRITICAL MINERALS 2020

Critical minerals are essential for modern technology and clean energy transition. Australia's economic resources increased for many critical minerals in 2020:



The Greenlight Project is a year-long look at how regional Australia is preparing for and adapting to climate change. Fresh Greenlight stories are published regularly at cosmosmagazine.com

It also puts the nation in a powerful spot, adds Huggins: "This positions Australia as the main contender in the critical minerals sector on a global scale."

Well-established mining regions cover just 20% of Australia. The remaining 80% remains largely under-explored.

Part of the problem has been a matter of scale. Big iron and copper mining operations, for example, can see the extraction of affiliated critical minerals as an unwanted complication. And smaller miners find it hard to raise capital for crucial equipment.

Now moves are afoot to change this.

Unfinished business

Some $2 billion has been set aside under the 2022 Critical Minerals Strategy to help small and medium-sized Australian companies get off the ground.

"More investments, especially from smaller and mid-tier mining and exploration companies to increase production and meet global supply chain demands will help Australia lead the way in critical minerals supply by 2030," Huggins says.

Performance Partners is involved in several projects seeking to keep the critical minerals process as clean as possible. One involves sifting through the tailings of an old mining site, with 70% of its power needs being met by solar and wind generators. Another is a greenfield mining project determined to establish its carbon net-zero credentials from the outset.

"Incentivising programs and encouraging mining companies to install or repurpose existing facilities to produce critical minerals would enhance Australia's role in stabilising the critical mineral supply chain market," says Huggins.

"These factors, riding on the backbone of Australia's reputation for environmentally and socially responsible governance, would propel Australia into being at the forefront of the critical minerals mining sector."

The mining industry is aware that Australia – and the world – will be watching this dramatic increase in mining actively closely, he adds. And that means clean technologies must be adopted quickly along with adherence to ESG (environmental, social, and governance) standards.

"Australia can attest to sourcing for minerals in environmentally and socially responsible ways with its strong and efficient regulatory environment. Workers involved in the sector are also protected," Huggins says. "This sets Australia apart from its competitors that may operate at a lower cost, but at the expense of the environment or its workforce." ⊙

JAMIE SEIDEL is based in Adelaide. His story on quantum engineering appeared last issue.

DOWNWARD

The nautilus's lineage made it through all five of Earth's previous mass extinctions, writes **KATE EVANS.** But can it survive the Anthropocene?

DAVE ABBOTT

SPIRAL

The nautilus inhabited the deep waters surrounding forest-clad Manus Island, an exclamation point at the northwestern end of Papua New Guinea's Bismarck Archipelago.

It lived slowly and in near-complete darkness, its large eyes tuned to the blue wavelengths of bioluminescent bacteria that signalled a carcass to scavenge, and just sensitive enough to tell night from day 300 metres below the surface. Its 90 tentacles and superlative sense of smell aided its search for food along the sea floor. And as it grew, it added new chambers to its spiralling shell.

When the nautilus died – at perhaps 20 or 30 years of age – its soft, squid-like body rotted away. Its shell lost the neutral buoyancy that allowed it to cruise effortlessly at whatever depth it chose, and it floated to the surface.

Currents washed it into the mangroves, or onto one of Manus's palm-fringed beaches, or perhaps onto a coral-ringed atoll group 4 km south east, called Ndrova. Wherever it landed, the shell's elegant cream whorl with rust-brown stripes would have caught the woman's eye and she took it home with her.

Manuai Matawai grew up watching his mother, like the other women in his fishing village, use the nautilus shell's sealed outer chamber as a scoop for separating coconut oil from the fruit's starch at the bottom of her cookpot. But like most in his coastal community, he had never seen one alive, because of its preference for the cold, dark depths.

Then, in 2015, researchers from Australia and the United States came to study the creature, and Matawai, then working for The Nature Conservancy (TNC), helped organise their expedition to Ndrova. Peter Ward, a paleobiologist at the University of Washington widely known as "Professor Nautilus", had last visited in 1984, when he and a collaborator were among the first people to examine a live fuzzy nautilus, a species belonging to a new genus that they later named *Allonautilus scrobiculatus*.

Ward and his colleagues had come back to see if the fuzzy nautilus and the better-known chambered nautilus (*Nautilus pompilius*) were still there, and to try some new research tools.

Only a handful of scientists study nautiluses, and many of the most basic questions about the creatures' lives haven't been resolved. And yet, they have captivated humans for centuries, their shape inspiring art and architecture across many cultures.

The underwater ship in *20,000 Leagues Under the Sea* was called *Nautilus*, as was the first nuclear submarine. Today, numerous companies, from wineries to exercise-machine manufacturers, also employ the name.

"I don't know if it's the most mysterious well-known animal or the most well-known mysterious animal," says Gregory Barord, who joined the 2015 expedition led by Ward.

Soon after Ward hauled on his dive gear and descended the steep reef walls, he noticed changes. In 1984, the scientists had been harried by sharks.

"They were nasty, cranky little bastards, so I was kind of dreading going through that again," Ward recalls. This time, they didn't see a single one. There was also evidence of coral bleaching, and waters that had been cool below the shallows now felt uncomfortably warm.

Climate change is altering life in our oceans, and extreme heat is now normal in many places. Ward believes nautiluses may already be seeking refuge in cooler, deeper waters to cope. But there is only so far the molluscs will be able to swim. Below 800 metres ,the pressure is enough to make their shells implode.

At the same time, human desire for the animals' beautiful mother-of-pearl shell has led to overfishing in some parts of their tropical Pacific home.

"It's the nautilus's bad luck that it's got this beautiful symmetry," says Ward. Between 2005 and 2014, trade data collected by the US Fish and Wildlife Service indicated that more than 100,000 whole nautilus shells and 800,000 parts were imported into the US alone. Some once-abundant populations in the Philippines – where nautiluses are also occasionally hunted for food – may already be extinct. Can they survive us?

Researchers (from right) Manuai Matawai, Peter Ward, Gregory Barord, and Peter Kanawi snorkel in search of nautiluses off Ndrova. Opposite; Barord returning nautiluses for release

LEFT: MANUAI MATAWAI. ABOVE: PETER WARD

> “I DON’T KNOW IF IT’S THE MOST MYSTERIOUS WELL-KNOWN ANIMAL OR THE MOST WELL-KNOWN MYSTERIOUS ANIMAL.”

AGE-OLD ANCESTRY

Nautiluses have certainly always been survivors. Ancient and cunning, their lineage was adaptable enough to persist through all five of Earth’s major past extinction events. Their ancestors, the nautiloids, appeared half a billion years ago. They were the first cephalopods, a group of molluscs that today includes octopuses, cuttlefish, and squids.

Back then, most life crawled along the sea floor, but the nautiloids were able to float suspended in the water – a key innovation they achieved by removing liquid from their innermost chambers to match the density of the seawater around them, rendering them essentially weightless. The earliest nautiloids had straight, conical shells, but they soon evolved the coiled spiral with interconnected internal chambers seen today. In their current incarnation, nautiluses have cruised the oceans for at least 100 million years.

It was in this shape that they weathered the asteroid that ended the age of the dinosaurs. Debris from the impact and ash from the fires that raged afterwards obscured the sun for two years, killing most of the photosynthesising plankton that formed the basis of the food web in the shallows. Nautilus species that lived near the surface likely starved into extinction along with their relatives, the ammonites.

But in the perpetual twilight known as the Mesopelagic Zone, between 200 to 1,000 metres

> “AT DAWN, THEY’D HAUL THE ROPES UP BY HAND – A GRUELLING WORKOUT THAT TOOK NEARLY AN HOUR PER TRAP

below the surface, other nautilus species persisted. And because today’s nautiluses are thought to be mainly scavengers, the mass death and destruction may even have benefited them, suggests Ward.

After all, he says, “What was left after the Cretaceous was over? Dead bodies.”

The island of Ndrova is a particularly good spot for nautilus research: the sea floor drops away so sharply from its shores that a trap laid on the bottom hundreds of metres below the surface can simply be tied off to a coconut tree.

Ndrova’s chief, Peter Kanawi, welcomed the researchers, and 18 community members joined the expedition as assistants. Every evening around dusk the team set out in small motorboats and lowered the traps – cubic metal frames covered with chicken-wire and baited with tuna. At dawn, they’d haul the ropes up by hand – a gruelling workout that took nearly an hour per trap – stopping when the cage was within snorkelling distance of the surface.

The first night, the traps caught nothing. Some locals speculated that the foreigners hadn’t been properly introduced to the ancestors. But an elder fisherman who had been on the earlier expedition recalled that the traps had been set in a different spot in 1984, at a slightly shallower depth. On their next outing, the team did as he suggested.

In the morning, Richard Hamilton from TNC dove overboard to check the trap. “You feel like a little kid doing a lucky dip. It was all stuff I hadn’t seen before – sort of a visual appreciation of just how much you don’t know.”

Sometimes there were strange eels, and Hamilton particularly liked the “weird-looking crabs”. But that day, he was thrilled to count three fuzzy nautiluses and three chambered nautiluses.

Nautiluses are accustomed to the deep and can’t survive long in the warm surface waters of tropical seas. So once back aboard the outrigger, the scientists placed the animals in a seawater-filled cooler, chilled with frozen water bottles.

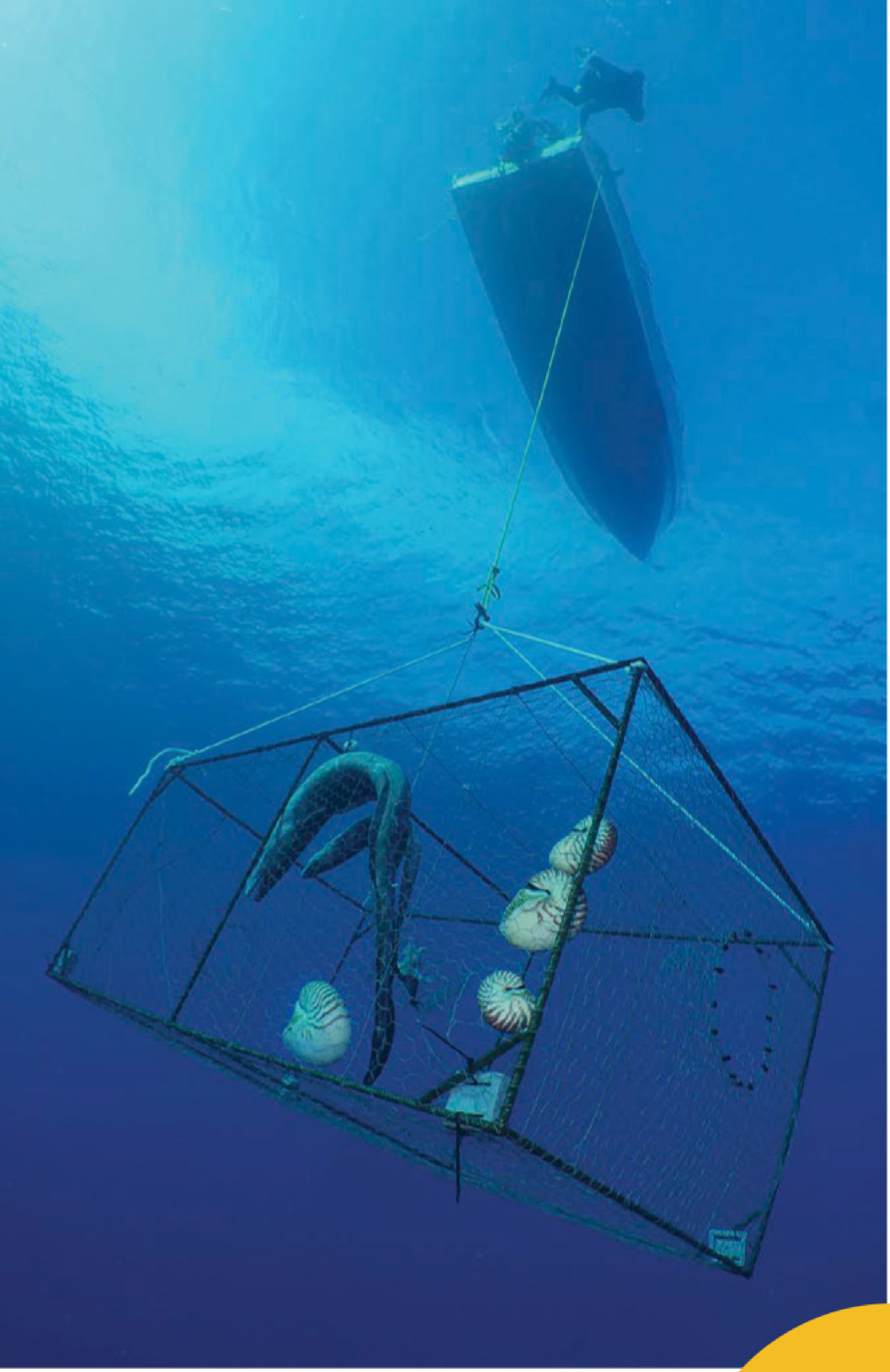
It was obvious which were the fuzzy nautiluses. Their shells were covered in a gooey, hairy periostracum, or outer layer, that’s completely absent in other types of nautilus. “It kind of feels like wet slimy fur,” says Barord.

Ward originally believed that the slime made it harder for predators to get a grip on the creature’s shell. But he now thinks it protects against breaks.

If a trigger fish bites a chambered nautilus and snaps off the outermost edge of its shell, the animal will lose its carefully calibrated neutral buoyancy and rise from the cool, comfortable depths.

“You go to the surface; you’re dead. The temperature will get you if the seabirds don’t get you first,” says Ward. If the same thing happens to a fuzzy nautilus, that crucial bit of shell won’t fall away; the fuzz holds it in place.

Ward and Barord carefully weighed and measured each nautilus. They also sexed them, which involved



Opposite, researchers pull up a trap – above, with four nautiluses lured by the bait fish inside – for analysis and study.

DAVE ABBOTT X2

turning the shell upside down until the animal emerged slightly, revealing the genitals. “It’s a boy!” Ward crowed.

In the past, researchers killed the nautiluses they caught, using whole shells for their work; Ward’s office is full of such items. By 2015, he had vowed not to kill any more. Instead, he broke off a sand grain-sized fragment of shell and clipped off a millimetre of tentacle for chemical and genetic analysis back in the lab.

Next, the scientists attached battery-powered transmitters to three of the creatures in their cooler. Since the 1980s, the devices had gotten much smaller – around the size of a AA battery – but they needed to be set into a low-density fibreglass saddle to ensure they did not affect the animal’s buoyancy. Matawai and Ward stuck the saddles to the nautiluses’ shells with epoxy resin and held them half-underwater while the glue dried.

Then, the researchers put on scuba gear and jumped over the side, upending each animal to release air pockets – “we burp ’em, we call it,” says Ward – before swimming them down about 30 metres and dropping them into the deep.

“For someone who depends on the ocean for survival,” Matawai says, “it was amazing to see what happens down there.”

For the next six days and five nights the team worked shifts, tracking the transmitter-wearing nautiluses in small aluminium fishing boats, without cover from glaring sun, squalls or evening winds, to find out more about their behaviour and habitat.

As the nautiluses went about their business on the sea floor between Ndrova and Manus, their transmitters sent sound waves up to the researchers’ receivers, recording each animal’s depth, its location, and the surrounding water temperature. Since the two species co-exist here, the experiment was also a chance to investigate differences in their behaviour.

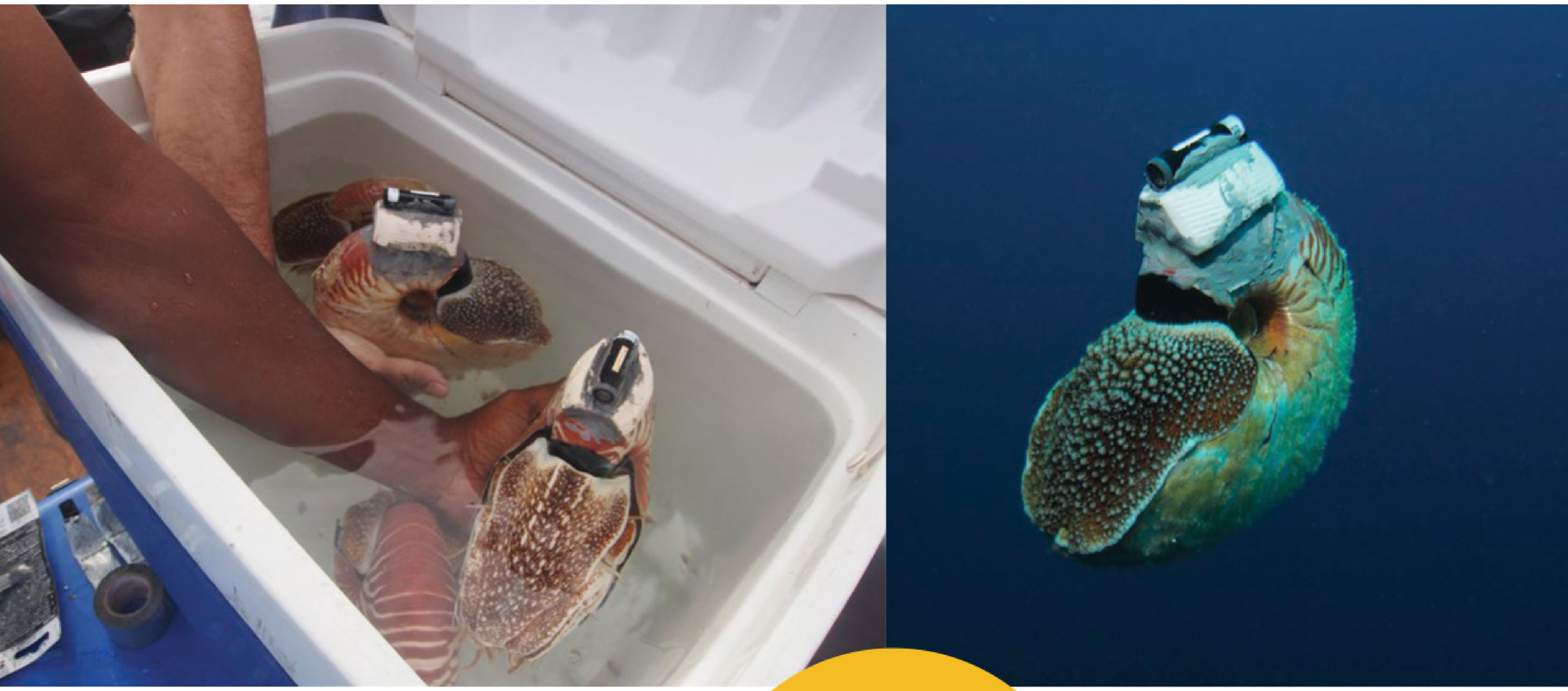
All three tagged nautiluses rose to around 100 metres during the night. But during the day, the two tagged fuzzy nautiluses dove to around 200 metres near the steep reef wall, while the chambered nautilus went out to the muddy plains at 300 metres, and even swam as far as the Manus mainland.

Previously, scientists had assumed they stuck to the sea floor and rarely travelled long distances. This newly revealed migration may bode well for nautiluses’ resilience against overfishing, Ward thinks, by allowing them to repopulate areas that have been cleaned out.

But in a warming sea, they may have fewer places to go. On land, climate change is already affecting the people of Manus Island, Matawai says. In December, king tides flooded some of the low-lying islands, drowning banana orchards and food gardens in saltwater. Underwater trends are less obvious, but average sea surface temperatures have risen consistently since the 1950s, and below 300 metres, the water is warming even faster.

In one recent study, researchers predicted that by the second half of the 21st century, “a rapid acceleration” of heating will occur throughout the water column, forcing animal populations to move into deeper water or closer to the poles to survive. They found that change is likely to happen fastest in the mesopelagic zone, 200–1,000 metres below the surface, where nautiluses make their home – and below which they cannot retreat. But even if the world’s governments take immediate meaningful action to cut greenhouse gas emissions, significant warming at these depths is probably already baked in.

So far, though, around Manus, the nautiluses



After determining the sex of each nautilus, opposite, radio transmitters attached to two, above left, allowed researchers to study the depth and movement of the species over days, learning that they travel much further than previously thought.

PETER WARD X2

seem to be adapting. Back in the lab in Seattle, Ward analysed his collection of Ndrova nautilus shells – some from 1984, the shell fragments from 2015, and a whole fuzzy nautilus shell he bought in a curio shop in Adelaide, which the owner said he'd picked up on Ndrova in 1975.

With a whole shell, you can take a chunk of each septum – the thin partition between the internal chambers – and the oxygen isotopes trapped within provide a record of the average sea temperature over the month or so the chamber took to form.

"So a shell is a 20- or 25-year record of temperature," Ward says. The tiny samples taken from 13 living animals' shells in 2015 provide a single data point – a snapshot of the sea temperature when their last chamber grew.

The results show the 1975 animal inhabited waters averaging between 12°C and 14°C, while those from 1984 and 2015 lived in temperatures of around 16°C. Ward was surprised the shells offered no evidence of warming water over those three decades, but says it's possible the nautiluses simply moved deeper to stay cool. The transmitters the team attached to the animals in 2015 record water temperature *and* depth, so in future experiments the living nautiluses may reveal with more certainty how their home might be changing.

The deepest part of the strait between Ndrova and Manus is only around 400 metres deep. If the warming continues, eventually the nautiluses must move somewhere new or perish. And while nautiluses have famously survived many periods of dramatic change, few have been as rapid as the one happening now. Even the so-called Great Dying that marked the boundary between the Permian and Triassic periods 250 million years ago took tens of thousands of years to unfold, says Jennifer Basil, a nautilus expert and behavioural ecologist at the City University of New York. "We're worse than the Permian extinction."

BEAUTIFUL BRAINS

What would be lost, if we lost the nautilus? Not just beauty, but brains, too. In the past, some marine biologists have dismissed nautiluses as "dumb snails", the least intelligent of the cephalopods. The suggestion greatly offends Basil, who has studied chambered nautiluses for more than 25 years. Her hair is a colour her students call "nautilus auburn", and she has nothing but enthusiasm for her subjects.

She and her doctoral students call them "the kids", and Basil says looking after them is like parenting a gang of troublesome 12-year-olds: " 'I'm gonna go out the outlet pipe. I'm gonna fight for some shrimp even though I have some.' They're always trying to injure themselves."

Basil studies animal brains and behaviour – hamsters, jays, lobsters – but she finds nautiluses particularly compelling because they can help answer questions about the evolution of intelligence. As a

“NAUTILUSES HAVE SMELL – ABLE TO DETECT LOW CONCENTRATIONS OF ODOURS AT DISTANCES OF MORE THAN 10 METRES

DAVE ABBOTT

group, cephalopods have the most grey matter of any invertebrate on Earth, Basil says – “big, fat, sassy brains” that evolved hundreds of millions of years before the vertebrate brain. But while octopuses, cuttlefish, and squid live fast and die young after laying 1000 eggs, nautiluses don’t mate until they are at least 10 years old, then lay a handful of eggs that take a year to hatch. “They are solving problems in a different way with a different brain,” Basil says

Basil’s early studies showed that nautiluses have superior powers of smell – they are able to detect very low concentrations of odours at distances of more than 10 metres, and move toward the source with great accuracy by comparing minute differences in the intensity of the odour reaching the receptors on each side of their body. In other words, they smell in stereo, an adaptation requiring complex sensory processing – a surprise in such an ancient animal.

Their eyesight isn’t bad, either. In another experiment, Basil and doctoral student Robyn Crook strapped each nautilus into a harness – dubbed the “nautilus car seat” – and exposed them to a flash of blue light, giving the animals some food immediately afterward. Just like Pavlov’s dog, the nautiluses learned to respond and continued to do so hours later, proving they have both short-term and long-term memory.

Reflecting on how well nautiluses hide their eggs – no one has ever seen them in the wild – Basil and Crook tested their spatial memory by putting them in a maze in a tank with uncomfortably shallow water. The nautiluses quickly found their way to a hole that led to deeper water by learning its association with a beacon made of bubble wrap and white tape. When Basil arranged some different objects pointing toward the hole instead, the nautiluses mastered that cue, too, even after the researchers put the beacon back elsewhere.

Finally, they turned the entire maze 180° so that Basil’s wall poster of 20th-century chemist Rosalind Franklin shifted relative to the hole. This time, the nautiluses went to the wrong place – the place the room told them to look, rather than the beacon. Basil and Crook were stunned.

The nautiluses’ confusion demonstrated their intellect. Rather than using simple, local cues, they were looking outside of their tank to consider global cues. In nature, those are much more reliable.

“That’s what’s so great about working with these guys. They always surprise you. They’re always more capable than you thought,” says Basil. “And they have illuminated the history of big brains in a way that wouldn’t have been possible with any other lineage.”

Although Barord and Ward have spent more time with nautiluses in their natural habitat, Basil perhaps knows them more intimately. Number 3 was the teacher’s pet. Number 13 was always trying to break out of her car seat. Number 9 lived the longest in captivity, 10 years, and he was Basil’s favourite: “Oh, he was a prince.”

He would curl his tentacles around her finger when she reached into the water, and when he got old, Basil gave him a “retirement tank” and his favourite food – lobster carapaces she scrounged from fancy New York restaurants.

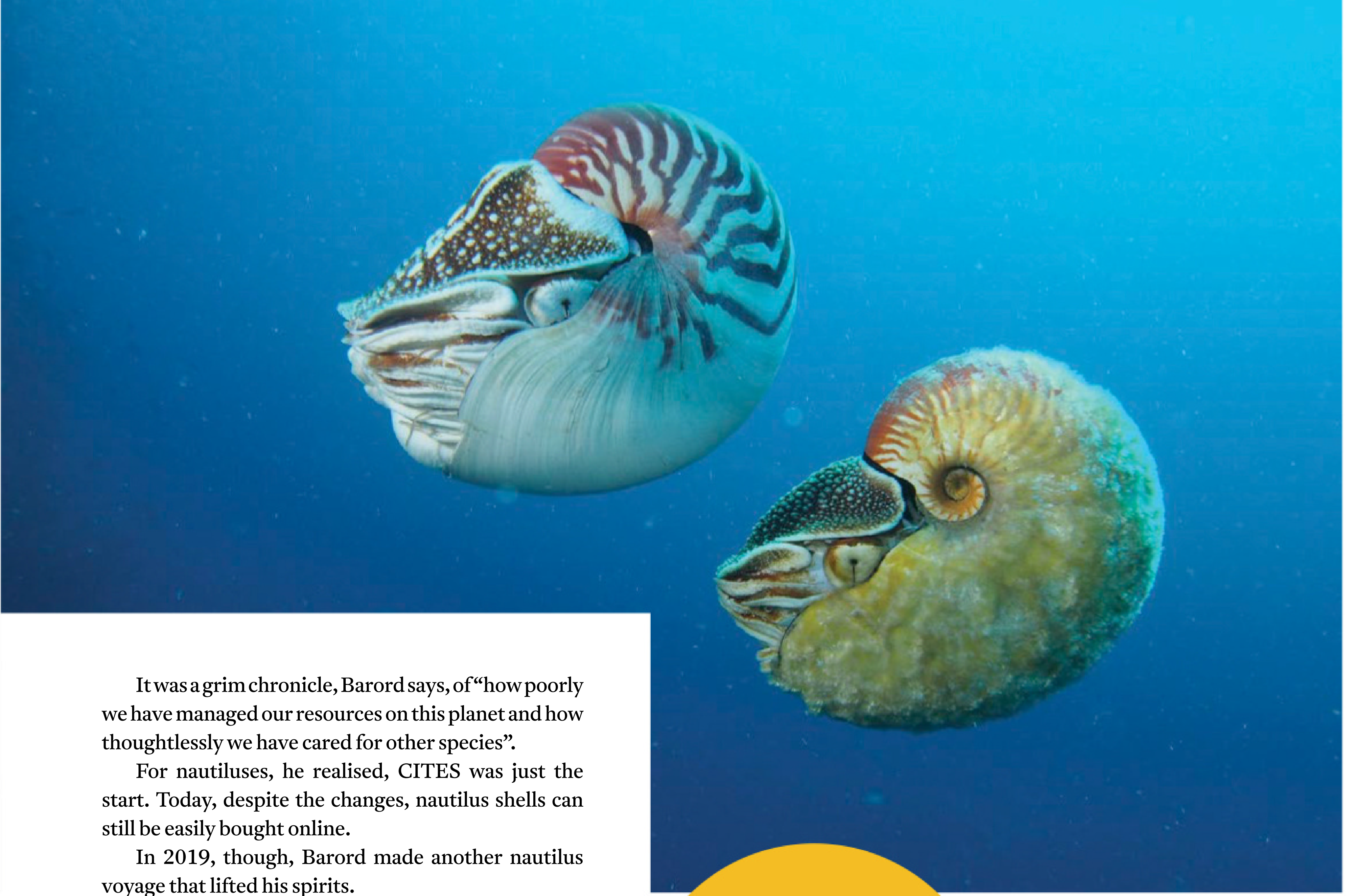
Basil was “broken up” after he died (she still has his shell). The inevitable emotional attachment is the joy of studying these remarkable creatures, she says – and the steep price of facing their possible disappearance.

FUZZY FUTURE

In September 2016, Barord sat amid a crowd of international delegates and representatives of NGOs in a conference centre in Johannesburg, South Africa. He, Ward, Basil, and other nautilus researchers had put in years of work alongside officials from the governments of Fiji, India, Palau, and the US to get the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) to require permits for commercial export of any nautiluses.

In theory such regulation would reduce fishing pressure by limiting international trade. The chair made the announcement adding the nautilus to the list along with the litany of animals in trouble – the silky shark, thresher sharks, all nine species of devil ray.

> “THESE TINY LITTLE BEHAVIOURAL CHANGES… IT'S NOT A HUGE THING THAT THEY'RE CHANGING. THEY'RE JUST TWEAKING”



Opposite, Ndrova Chief Peter Kanawi holds the two co-existing species of nautilus – *Allonautilus scrobiculatus* and *Nautilus pompilius*, above – found off his island's coast.

PETER WARD X2

It was a grim chronicle, Barord says, of "how poorly we have managed our resources on this planet and how thoughtlessly we have cared for other species".

For nautiluses, he realised, CITES was just the start. Today, despite the changes, nautilus shells can still be easily bought online.

In 2019, though, Barord made another nautilus voyage that lifted his spirits.

This time, he and Hamilton travelled to Marovo Lagoon, a dazzling archipelago of palm-studded, coralline islets in the Western Province of the Solomon Islands, a Pacific nation to the east of Papua New Guinea. No scientist had found fuzzy nautiluses alive there before, but their shells had long washed up on beaches, and Hamilton had seen some displayed in a bar in nearby Isabel Province.

Every evening, alongside the chicken-wire fish traps, they dropped a lighted camera trap called a Baited Remote Underwater Video Station (BRUV) in hopes of collecting the first-ever film of a fuzzy nautilus in its habitat.

Soon, they had caught both fuzzy nautiluses and chambered nautiluses in the live traps. The team had proven that both species live in the Solomons, and had found only the second place after Ndrova where the two types are known to co-exist.

Ashore on a nearby island, Barord loaded the footage from the video traps onto a small camcorder. A fuzzy nautilus and a chambered nautilus were swimming around together, attracted by the bait. The fuzzy nautilus not only looked scruffier than the chambered one, it moved more slowly. Researchers had noticed this difference between the two species before, but for Barord, seeing them together in real time was a revelation.

"It was acting differently in its environment," Barord says. "It just kind of connected for me how these animals have been able to survive for this long. These tiny little behavioural changes… it's not a huge thing that they're changing. They're just tweaking, calibrating a little bit." Smooth shell, fuzzy shell. Shallower, deeper. Faster, slower.

"It's hard for me to envision 500 million years, but these little changes in these two different genera just put it all into perspective for me of how they've been able to adapt in a very different way than other animals have."

The moment filled Barord with hope for the nautilus's resilience.

Manuai Matawai shares that hope. Hanging on the wall of his home on Manus Island is a banner emblazoned with the distinctive coil of a nautilus shell. It is the flag of the Win Nation, Matawai explains, a syncretic spiritual group consisting of followers of the late prophet Sir Paliau Moloat.

The nautilus's shell symbolises a vessel, Matawai says. The soft body of the animal inside represents the people of the Win Nation. Protected by the shell, they sail forth into eternity, guided by the stars. It makes sense, as an emblem: a mysterious creature that has existed in various forms for half a billion years is about as close to immortality as life on Earth gets. Perhaps, nautiluses will soon be gone. Or perhaps, against all odds, they will be around for half a billion more. ◉

This is an edited version of a story from *Biographic*, the magazine of the California Academy of Sciences.

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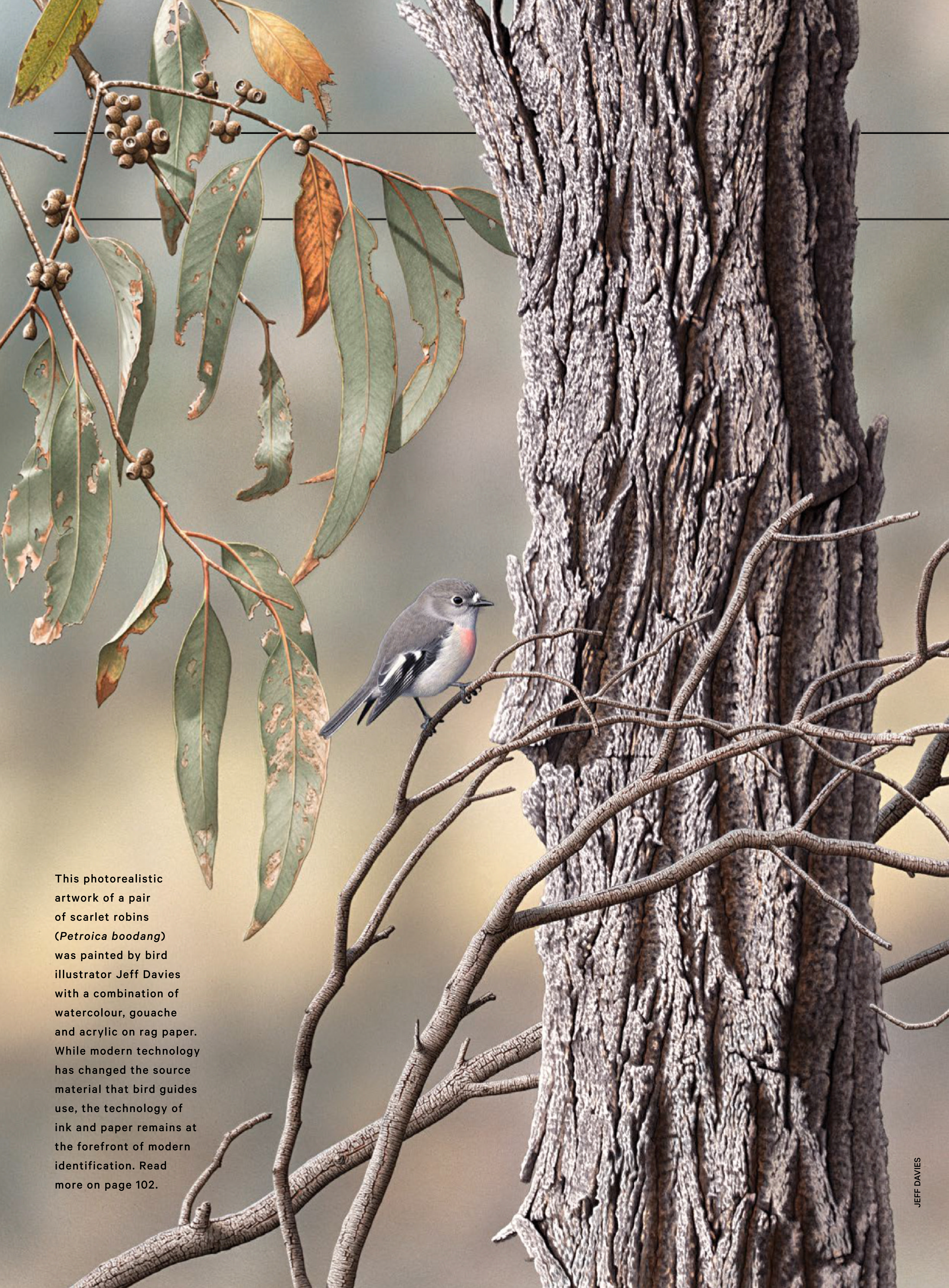
This photorealistic artwork of a pair of scarlet robins (*Petroica boodang*) was painted by bird illustrator Jeff Davies with a combination of watercolour, gouache and acrylic on rag paper. While modern technology has changed the source material that bird guides use, the technology of ink and paper remains at the forefront of modern identification. Read more on page 102.

JEFF DAVIES

ZEITGEIST

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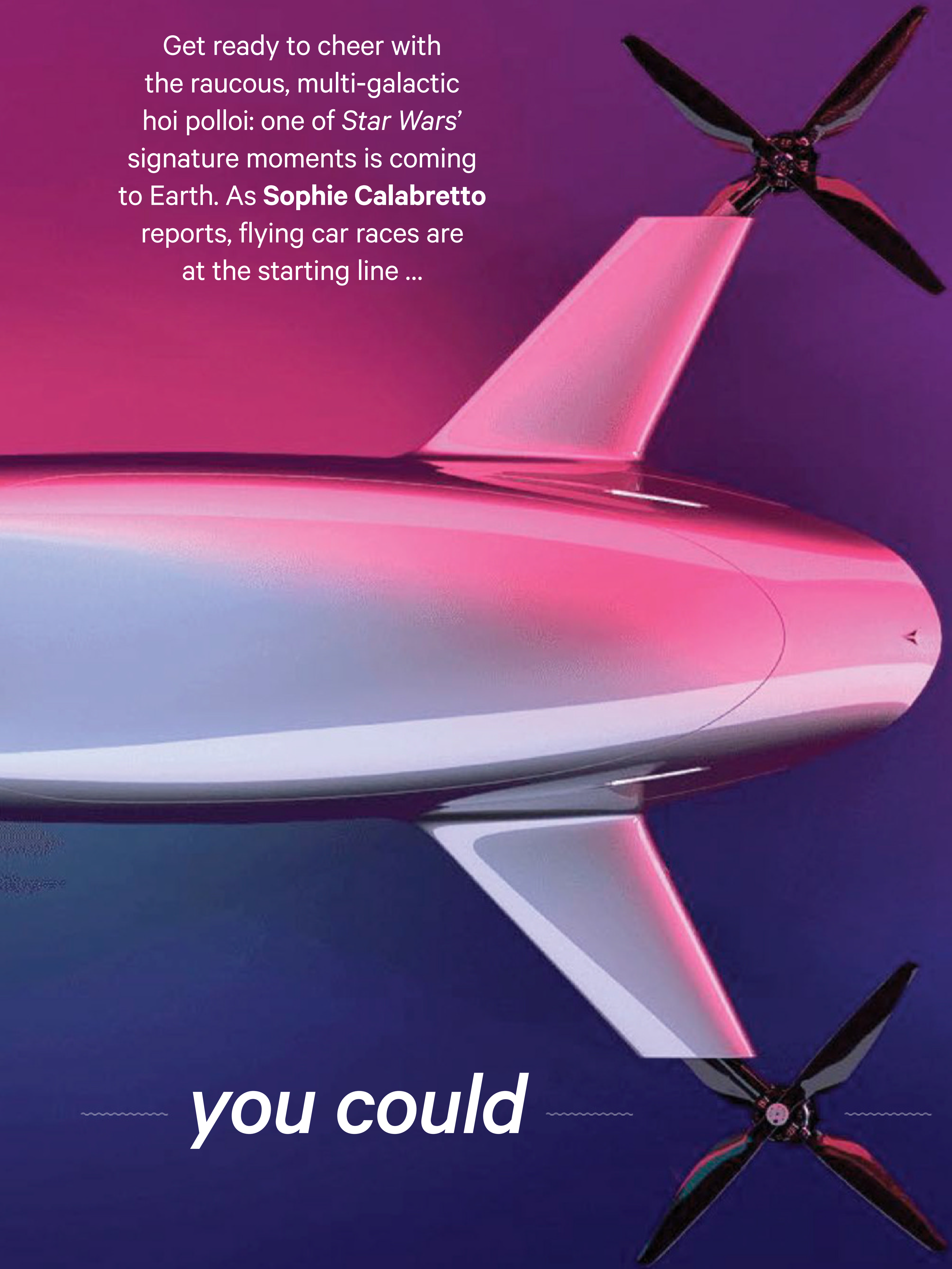
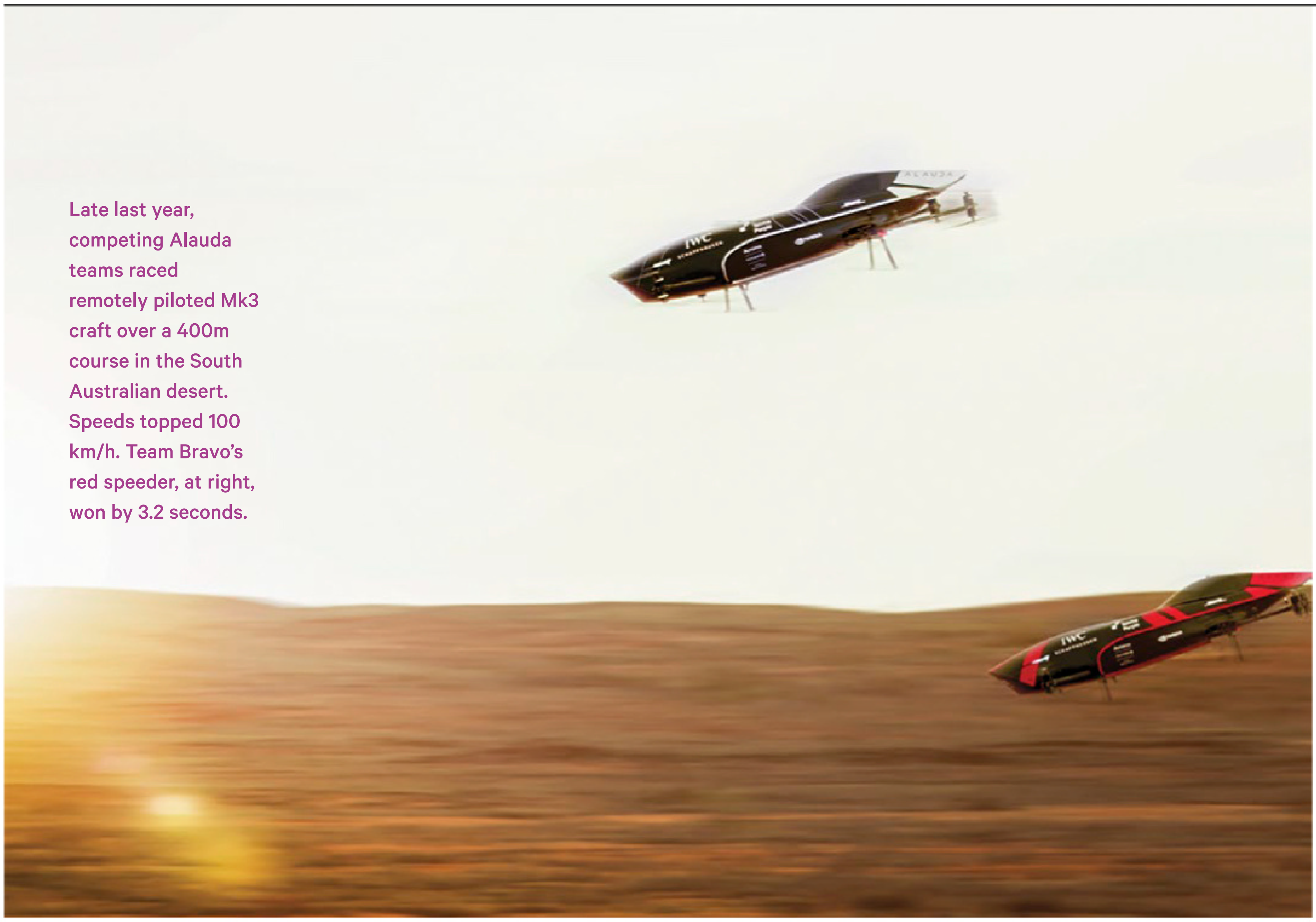


Get ready to cheer with the raucous, multi-galactic hoi polloi: one of *Star Wars*' signature moments is coming to Earth. As **Sophie Calabretto** reports, flying car races are at the starting line …

you could fly?



Late last year, competing Alauda teams raced remotely piloted Mk3 craft over a 400m course in the South Australian desert. Speeds topped 100 km/h. Team Bravo's red speeder, at right, won by 3.2 seconds.

In what is one of the most delightful examples of life imitating art, Tatooine's Boonta Eve Classic is coming to Australia. If all goes to plan, we've finally reached that moment in history when *Star Wars* and F1 fans can unite in the South Australian desert, for the world's first racing series for electric flying cars: Airspeeder.

While flying cars have been creeping closer to reality (see "Dude, where's my flying car?", Cosmos 91) they still sound like something out of science fiction. But they're exactly what Alauda Aeronautics is promising: "Flying cars that anyone can own and anyone can fly."

Founded by Matt Pearson in 2016, Alauda is Airspeeder's engineering arm and is responsible for developing and building the performance electric vertical take-off and landing (eVTOL) vehicles for this ambitious racing series.

Air racing has a long and rich history. The first record is in 1909 at the Prix de Lagatinerie. Between 30,000 and 60,000 people are estimated to have turned up to watch four biplanes complete 10 laps of a 1.2 km course in the shortest time possible. Stops were allowed, and with no one able to complete the race, Léon Delagrange was declared the victor as he made it the farthest: almost five laps in just over 10 minutes. The planes were flimsy, unable to fly in moderate winds or take off on unmown grass, and had a tendency to overheat after a few minutes. Most early races were held in France, with the notable exception of the Schneider Trophy, a seaplane contest that ran in various locations around the world from 1913 to 1931. After World War II formula races were conceived in the US, in which small manoeuvrable planes raced around a circuit defined by pylons. This century, Red Bull has added to the excitement with airborne obstacle races in which pilots navigate over, under and around brightly-coloured objects at high speed and low altitude.

> "This gives pilots the control to make the same sharp hairpin-style turns as a Formula 1 car, but with an added bonus"

The need for speed

Now comes the next generation. Airspeeder's EXA Series, the remotely piloted, uncrewed flying race series, are like something only seen in sci-fi movies.

From Mark 1 (Mk1) to the currently under-development Mk4, the evolution of Airspeeder's vehicles has allowed for the testing of theories, procedures, and functionality in the lead up to this out-of-this world racing series.

"Mk2 was a demonstration vehicle that got people excited about the concept, and then Mk3, which we currently have and will be racing uncrewed, is the vehicle that we'll be using in the EXA Series," explains Brett Hill, Technical Project Manager at Airspeeder.

Airspeeder's EXA craft are sleekly painted structures that look a little like

COURTESY AIRSPEEDER

a mini-sized jet cockpit attached to a maxi-sized camera drone. Unlike Anakin Skywalker's podracer – which, although built by a nine-year-old, had a garage-full of envy-inciting tech, including a custom pair of engines that used Repulsorlift technology (which creates fields of negative gravity that push against a planet's natural gravitational field to create lift) – Airspeeder's Mk3 contains some more familiar, though impressively dangerous-looking, components. The lift and power comes from a coaxial octocopter (the 'octo' here indicating the eight lift-generating rotors) in EXA's "octocopter X formation", with each two-blade rotor powered by its own motor and arranged in an X-shape if you're looking top down.

The overall effect is like looking at the super sleek lovechild of a *Dune* ornithopter and the multirotor drone this adult was gifted for her last birthday; something out of science fiction, but dangerously within grasp.

Airspeeder's octocopter X formation is paired with a 96kW electric powertrain (the system that generates and delivers power to electric vehicles). This gives pilots the control to make the same sharp hairpin-style turns as a Formula 1 car, but with an added bonus – they can move up and down along the vertical axis as well. The Mk3 has a carbon-fibre frame and fuselage, which makes it strong, stiff and lightweight. Size matters: with an uncrewed weight of 100kg, manoeuvrability is key.

The first-ever timed electric flying car drag race took place in northern outback South Australia last November. Two Mk3 teams (Alpha and Bravo) competed in a 400m race to the finish line, flying 10m above the ground, getting above 100 km/h over this short distance. Team Bravo crossed

The electric-powered Alauda Mk3 (above and below) was test flown in SA. Australia's Civil Aviation Safety Authority observed the flights and certified the aircraft. The crafts' airframes contain a 96kW electric powertrain that, its makers say, has a greater thrust-to-weight ratio than a jet fighter's.

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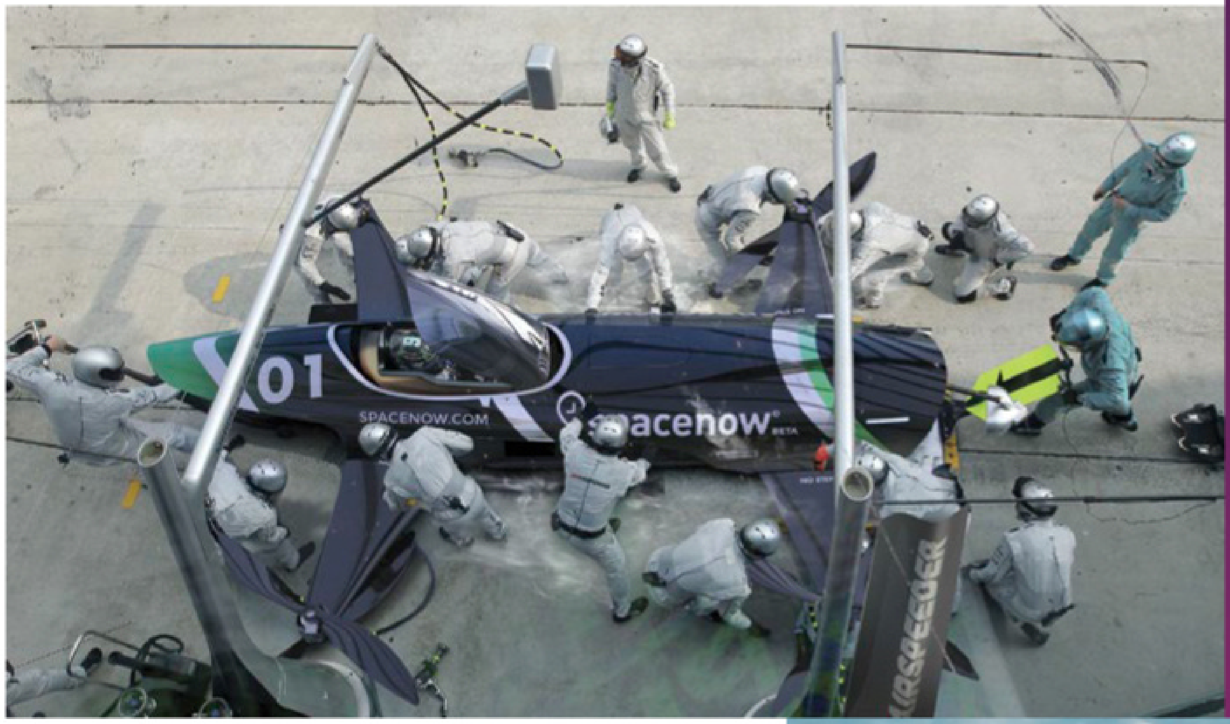


The Airspeeder series promise Grand Prix-like scenes (left) with an elevated experience. Pilots will train on a simulator (concept sketch, opposite top) but for now remotely piloted craft (below, and opposite below) are ruling the flight test agenda.

the line a whopping 3.2 seconds faster than Team Alpha, showing that nomenclature can be arbitrary, and it takes no prisoners. F1 fans might feel this victory particularly keenly, as South Australia lost its Grand Prix to the east some years ago, and has never quite recovered. (This race *flies*, Melbourne!)

No date has been set for the first public race, but Airspeeder hopes to launch them in coming months. The EXA Series anticipates three international races across 2023 in uncrewed vehicles, most likely to be held in North America, the Middle East, and Asia, with locations still to be locked down.

Once the uncrewed racing series is underway, the crewed series is set to follow.

"We've got a vehicle that is currently under development, and we expect to have the first crewed flight by the end of this year," says Hill.

"As the EXA Series takes off around the world, the engineering team can take our hands off that, and 2023 will be a big year of us designing the Mk4 and the next crewed vehicle."

> "Future craft will rely on a combination of throttle, joystick, and pedals, which allows pilots to control the speeders more as they would a fighter jet"

As part of the transition to crewed vehicles, Alauda is also working on the FPV (first-person view) system and integrating a new pilot control station and layout. Most traditional aircraft are steered by the HOTAS (hand on throttle and stick) system. Future craft will rely on a combination of throttle, joystick, and pedals, which allows pilots to control the speeders more as they would a fighter jet, rather than a standard FPV remote control.

This means the Mk4 can be raced uncrewed with the pilot on-ground in its first outings before using the same system inside the cockpit for later flights.

If it all sounds a bit risky, Alauda says the vehicles have 'virtual forcefields', using RADAR and LiDAR – a remote sensing technique that calculates variable distances by emitting beams of pulsed light – to deliver close but safe racing.

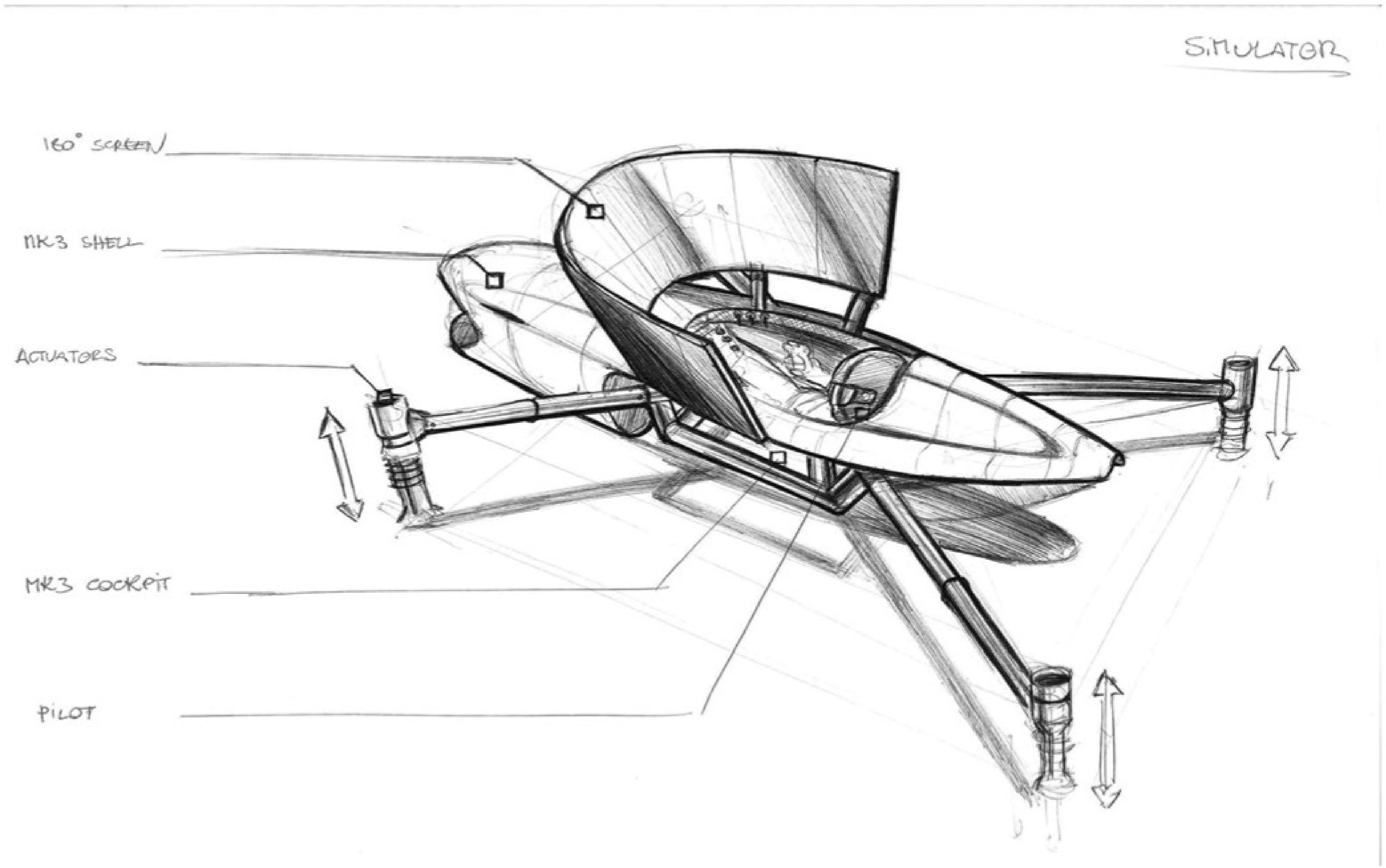
The first test flight of the crewed Mk4 is aimed for take off in 2024, with crewed racing events to follow in 2025. And if that sounds like a fantasy, luckily Alauda is in the dream-making business: "Making dreams into reality is, as an engineer, your job in life," says Hill.

But what about our dreams of owning a flying car?

Alauda's ultimate purpose extends to cars that can be "owned and flown by anyone", and they plans to have a commercial vehicle available to the public as part of the eVTOL market.

Even though the launch date is unknown, it's still hopeful news for flying car enthusiasts, and, according to Hill, everything is home-grown. "Our vehicles

COURTESY AIRSPEEDER



are designed, built, and then test flown in South Australia," he says.

The eVTOL sector is taking off: it's predicted to be worth more than $1.5 trillion by 2040. At the end of 2021, the South Australia Government announced a $20 million commitment to a dedicated space manufacturing hub – the Australian Space Park – in which Alauda Aeronautics will set up a new state-of-the-art factory. With the federal government kicking in an additional $20 million in funding, South Australia's growing reputation as the Space State seems well founded.

"We should have the philosophy of 'why not?' – why not? Why can't we do it here?" asks Hill.

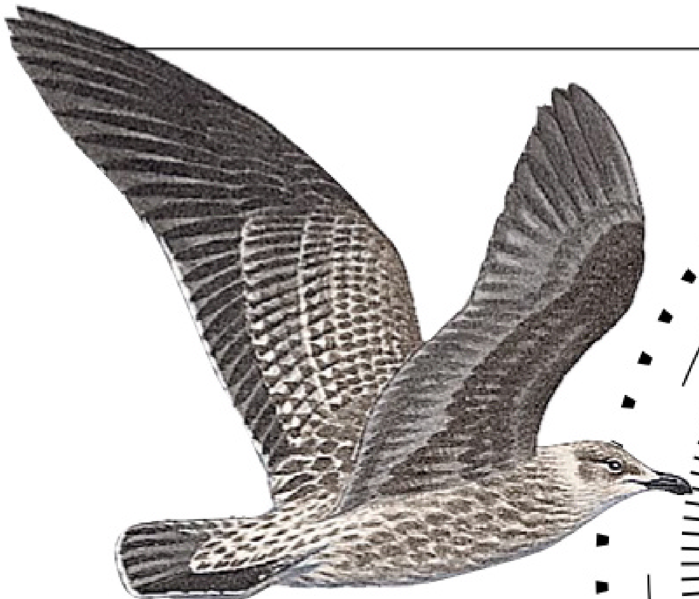
Indeed. In the meantime, I'd like to propose the reintroduction of slogan number plates in South Australia, in celebration of the state's rapidly growing eVTOL and aerospace industries, and in anticipation of my future flying car needing a cool number plate.

"SA – The Space State" has a nice ring to it, don't you think, Department for Infrastructure and Transport? Let's chat. ◉

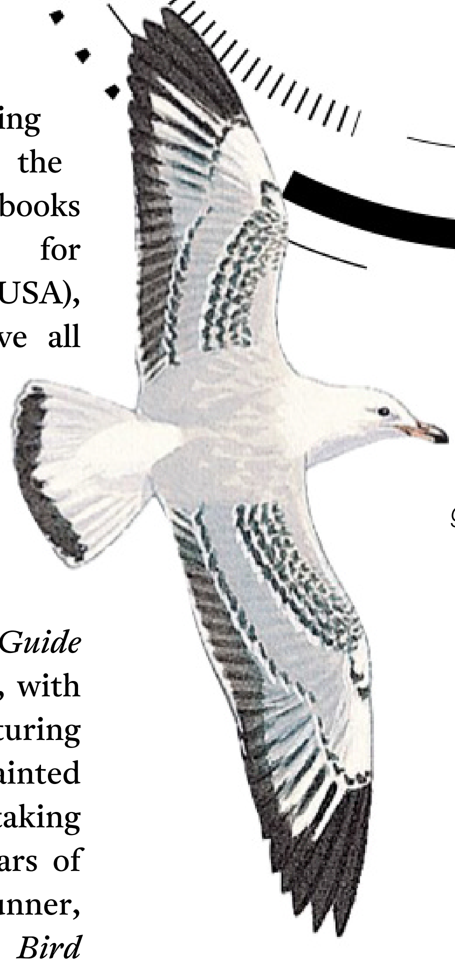
SOPHIE CALABRETTO is a mathematician specialising in fluid mechanics. Her last story, on stickiness, appeared in Issue 94.

COURTESY AIRSPEEDER

Taking flight



Electronics and digital imagery have transformed illustrated publishing over the past few decades – but one very particular genre has held out. By **Andrew Bain**.



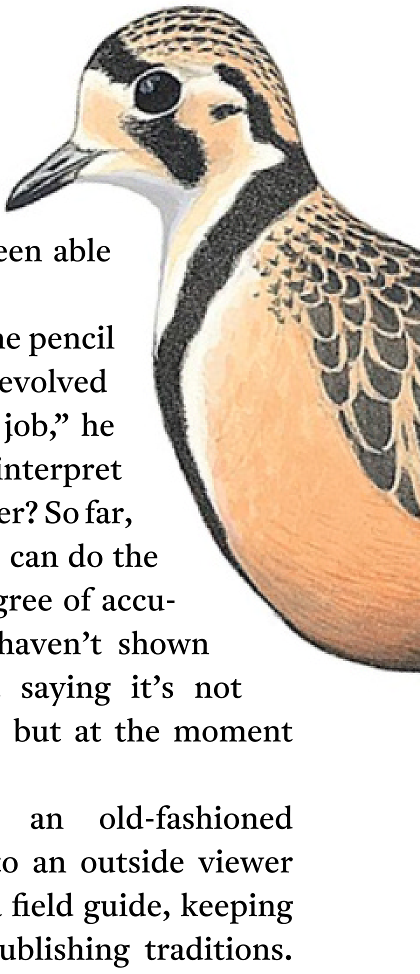
The world of book publishing hasn't been immune to the march of technology. Ebooks (which now account for around one in five book sales in the USA), audiobooks and self-publishing have all dragged the written word into the digital age. But when it comes to field guides, what's old is still new, with the timeless 'technologies' of pencil, paint and paper remaining at the forefront of the genre.

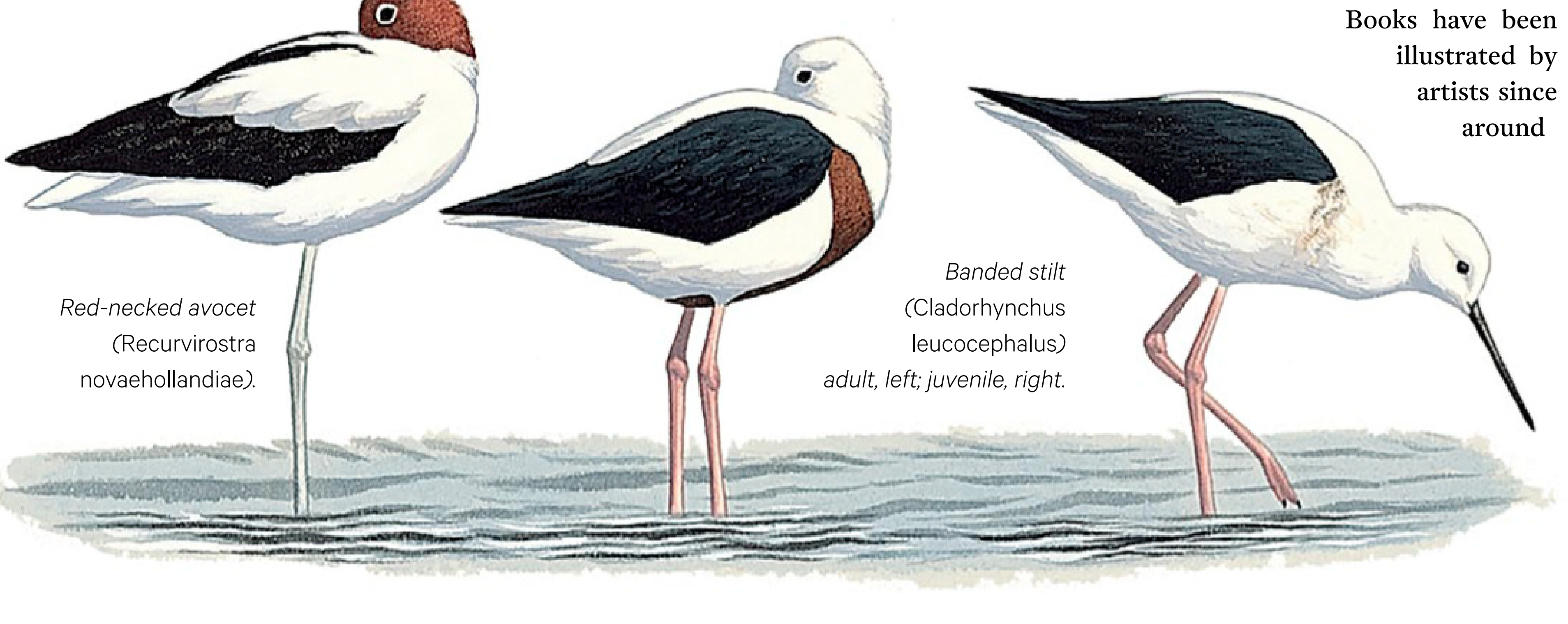
The Compact Australian Bird Guide was released by CSIRO this month, with the pocket-sized field guide featuring more than 700 hand-drawn and painted Australian bird species. It's a painstaking and exact process that requires years of work – the *Compact Guide*'s forerunner, the larger-format *The Australian Bird Guide*, was a nine-year project – but one that the principal artist for the two guides, Jeff Davies, says computer-generated imagery hasn't yet been able to supplant.

"The brush and the pencil and the tools have evolved to be perfect for the job," he says. "How do you reinterpret all that with a computer? So far, people out there who can do the work to the same degree of accuracy (on computer) haven't shown themselves. I'm not saying it's not possible with digital, but at the moment I'm not convinced."

Instead, there's an old-fashioned romance – at least to an outside viewer – to the creation of a field guide, keeping alive centuries-old publishing traditions. Books have been illustrated by artists since around

Above: Pacific gull (Larus pacificus) *juvenile and adult. Left: silver gull* (Chroicocephalus novaehollandiae). *Right: inland dotterel* (Peltohyas australis). *Opposite: sulphur-crested cockatoo* (Cacatua galerita); *long-billed corella* (Cacatua tenuirostris).

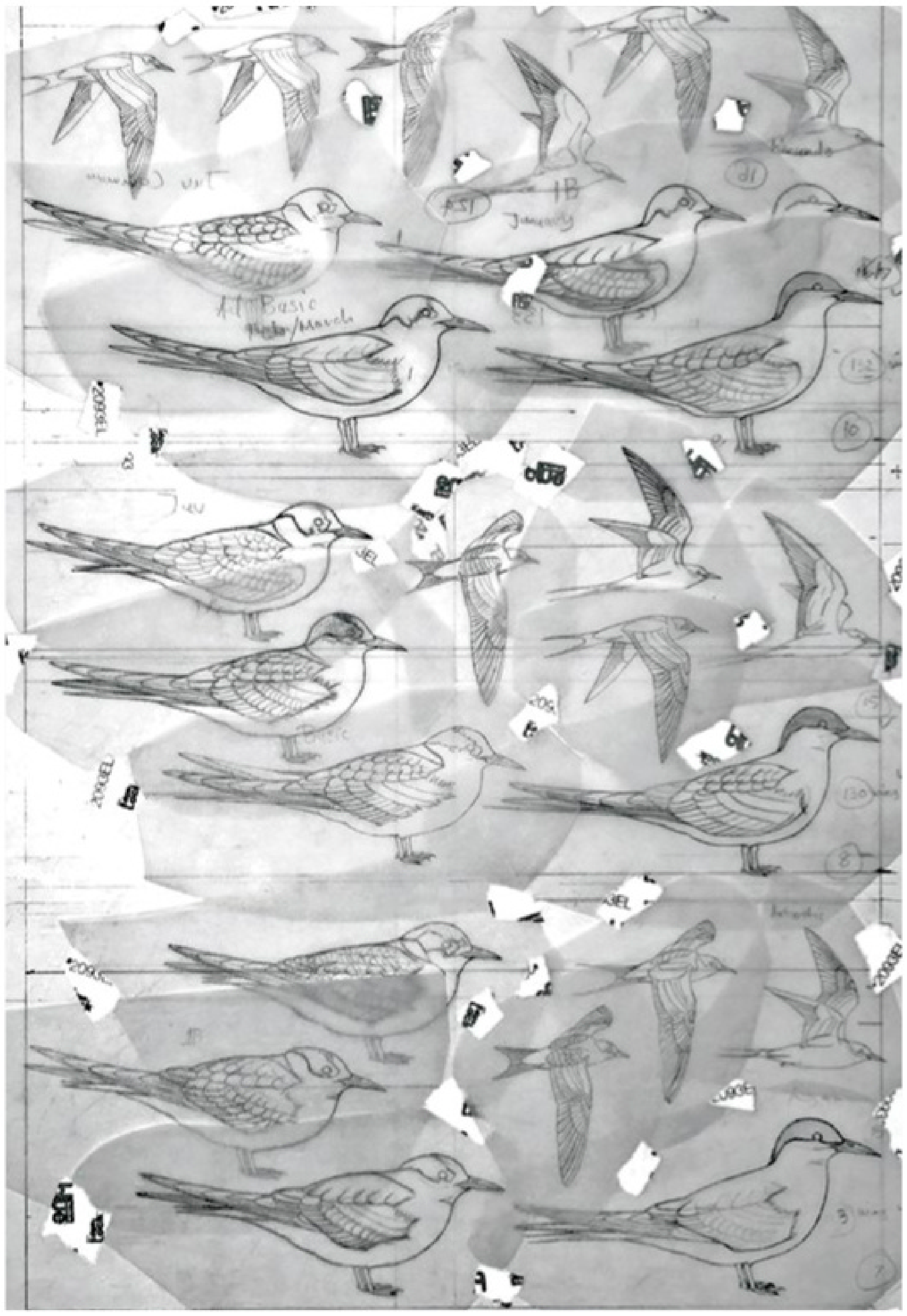


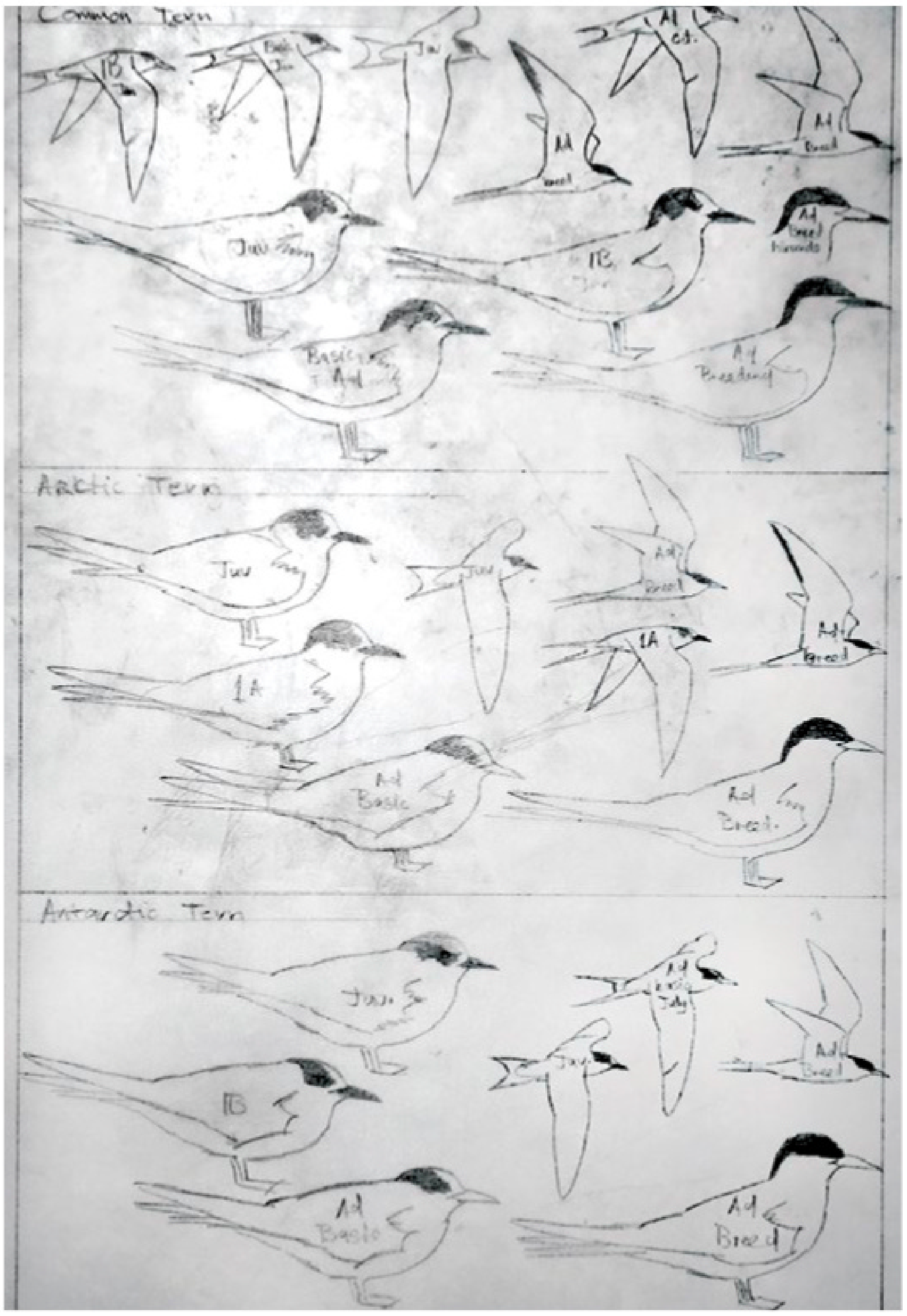


Red-necked avocet (Recurvirostra novaehollandiae).

Banded stilt (Cladorhynchus leucocephalus) *adult, left; juvenile, right.*

ALL IMAGES: JEFF DAVIES



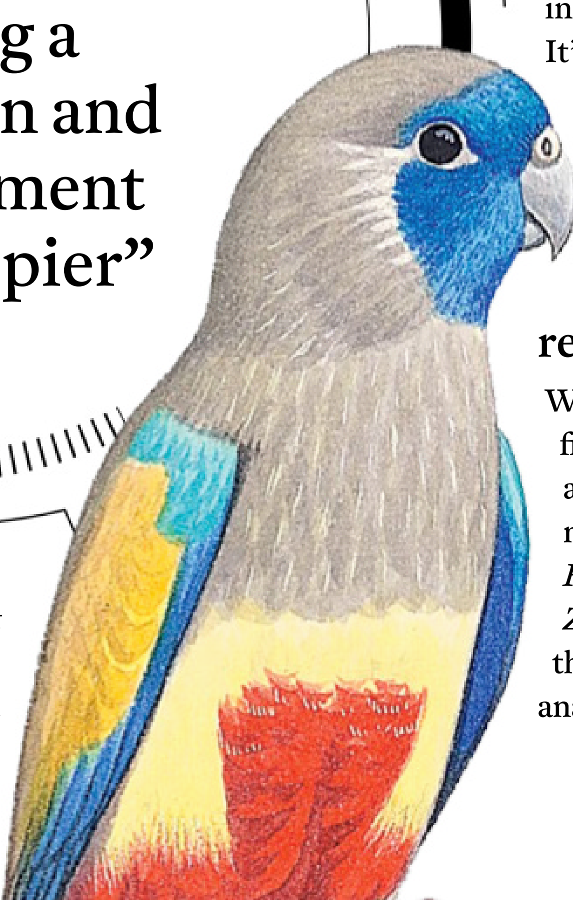


the 15th century, reaching an apex in the so-called Golden Age of Illustration – a period of around seven decades from 1850 when literature and illustration went hand in glove. It was during that era that what's considered the first illustrated field guide to birds was published – American ornithologist Florence Bailey's *Birds Through an Opera-Glass* (1890) – using simple line drawings to help readers identify and distinguish species.

It's a model that has survived to the present day, with artists like Davies and northern hemisphere counterparts including Ian Lewington, Hans Larsson, Dan Zetterström and Killian Mullarney spending days, and sometimes weeks, on a single image for the plates of a field guide.

> “The technology I used would go as far as having a reduction and enlargement photocopier”

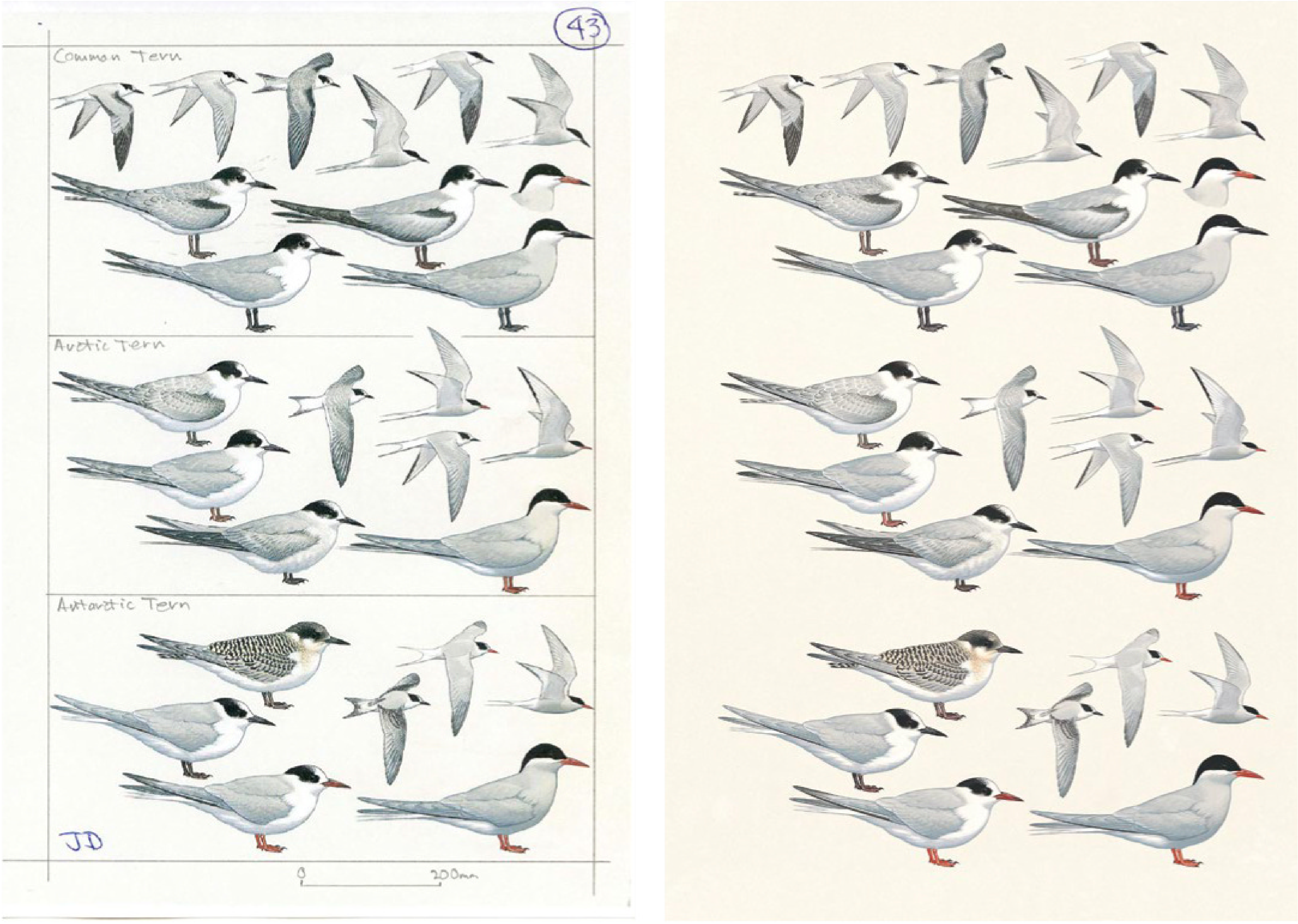
But there have also been significant advances in how the images are created. The age-old model of painting illustrations for field guides is now well and truly informed by other technologies. It's a change Davies has observed closely across his 35 years in the industry.



Greater bluebonnet (Northiella haematogaster).

The digital (photography) revolution

When Davies began illustrating field guides in 1987, working as the chief artist on the monolithic, seven-volume *Handbook of Australian, New Zealand and Antarctic Birds*, the entire process was largely analogue.

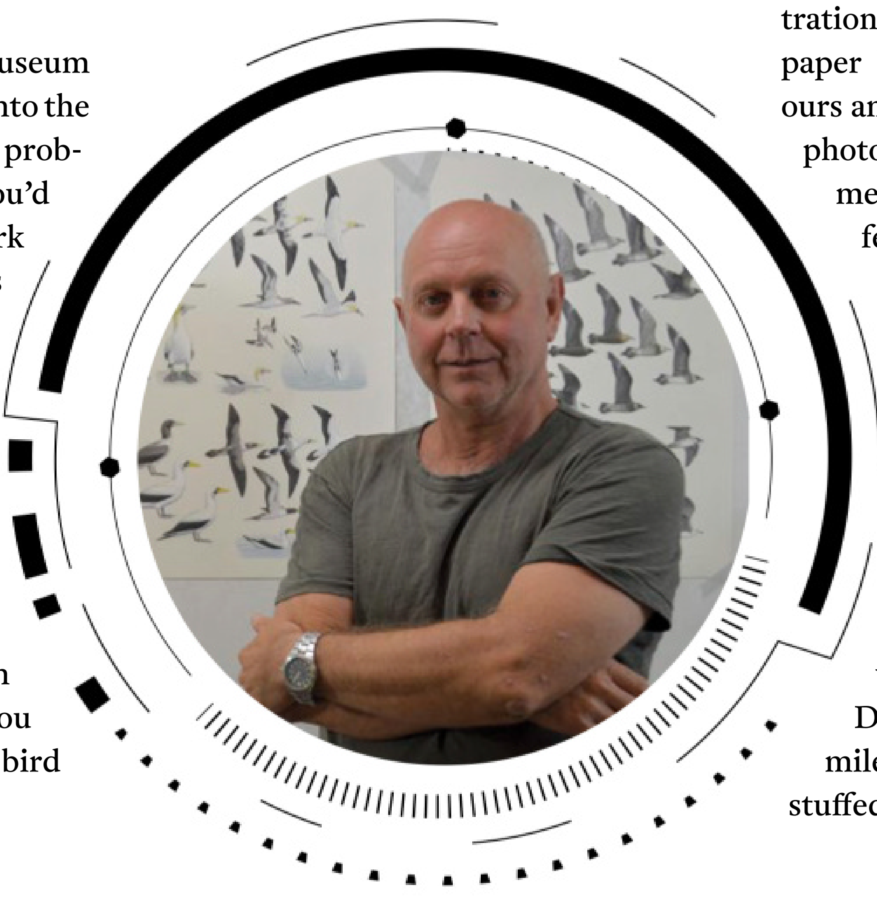


For Jeff Davies (below), illustrations begin (opposite top left) with drawings on tracing paper, then (opposite top right) page position sketches. Final paintings (above) are rendered in watercolour and gouache.

“The technology I used would go as far as having a reduction and enlargement photocopier,” says Davies. “I’d do my original drawing and then if I wanted to do another species, I could use those base drawings of one species to then go to another species just by adjusting the scale (on the photocopier).

“Basically, I was working from museum skins. That was when you had to go into the museum and look at specimens, and probably bring some specimens home. You’d try to look for photographs to work from, but all you had was a few slides and a few photographs in books.

“It was very difficult piecing it all together from specimens, especially when you’ve got birds like button quail where you’ve got a complicated plumage and pattern across the whole bird. And if every feather doesn’t sit in exactly its right position, the presentation of the bird doesn’t look right, so you have to get the topography of the bird really accurate.



“I spent all my time going into museums and then trying to work out how to get as accurate a drawing as possible, and by the time I’d finished and was ready to paint it, I only had about 10% of my time left – sometimes it would get down to that.”

For Davies, who begins each illustration as a series of drawings on tracing paper before painting them in watercolours and gouache, it’s the advent of digital photography that has revolutionised his methodology. Museum visits are now few, and access to source imagery is plentiful. Gone are the days when an artist might find a single image of a bird in the right position to help inform a painting. Instead, image libraries now abound with high-quality photos showing birds in a range of positions and angles.

“I’ve always wanted to get as close to the source as possible, which is the living bird,” says Davies. “So, for me, a photograph is miles more valuable than a dead bird stuffed in a drawer.

ALL IMAGES: JEFF DAVIES

Gang-gang cockatoo (Callocephalon fimbriatum).

"Before digital, people had cameras – but they didn't take many photos because you paid for every slide, basically, and then you had to take them in to get processed. Everything about slide photography meant that you weren't going to end up with millions of images.

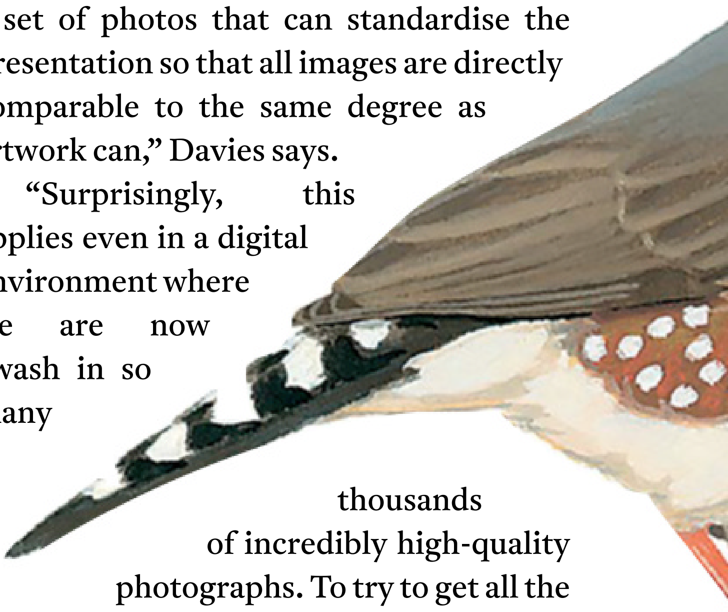
"When digital came along, any man and his dog could get a photo. For a few thousand dollars, you can get a really good camera, and they're so easy to use. They've now got eye-detection autofocus technology – all you have to do is point the camera in the general direction of a bird and it grabs the bird and focusses on the eye. It's led to a renaissance in our understanding of the visuals of birds, or anything else you want to look at."

Pied oystercatcher (Haematopus longirostris).

The past is the future … for now …

With such a bounty of wildlife photography, it begs the question: why not just use photos to illustrate field guides? A few guides do now employ photos instead of paintings, but most of the field guides that are considered classics – such as those published by Collins, National Geographic, Sibley and Peterson – still rely on artwork to portray species.

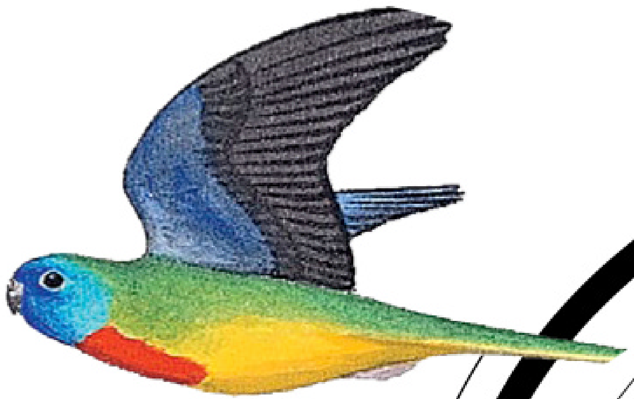
"It's really just not practical to collect a set of photos that can standardise the presentation so that all images are directly comparable to the same degree as artwork can," Davies says.

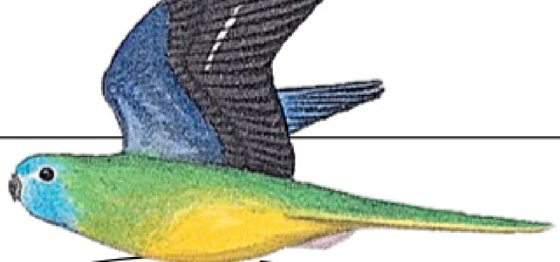


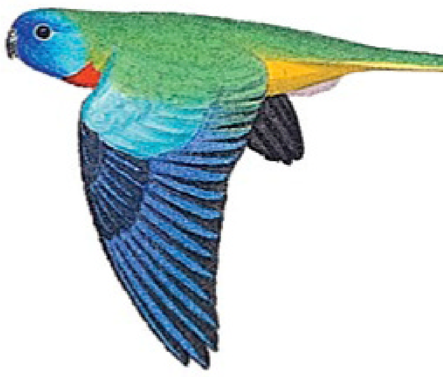
"Surprisingly, this applies even in a digital environment where we are now awash in so many thousands of incredibly high-quality photographs. To try to get all the birds lined up, all in exactly the same posture so they're directly comparable, in the same lighting conditions, it's just impossible.

"I also see illustrations evolving toward a distillation of showing only the essentials of what is required to represent an image. Artists leave out a lot of the unnecessary detail displayed in a photo which might otherwise leave a viewer wondering whether everything they see is important.

"A good illustration puts in only enough to create the essence of realism and aesthetic appeal and leaves the rest out. Photography can never compete with this aspect of the illustration process without substantial photo manipulation, in which case you may as well paint it."





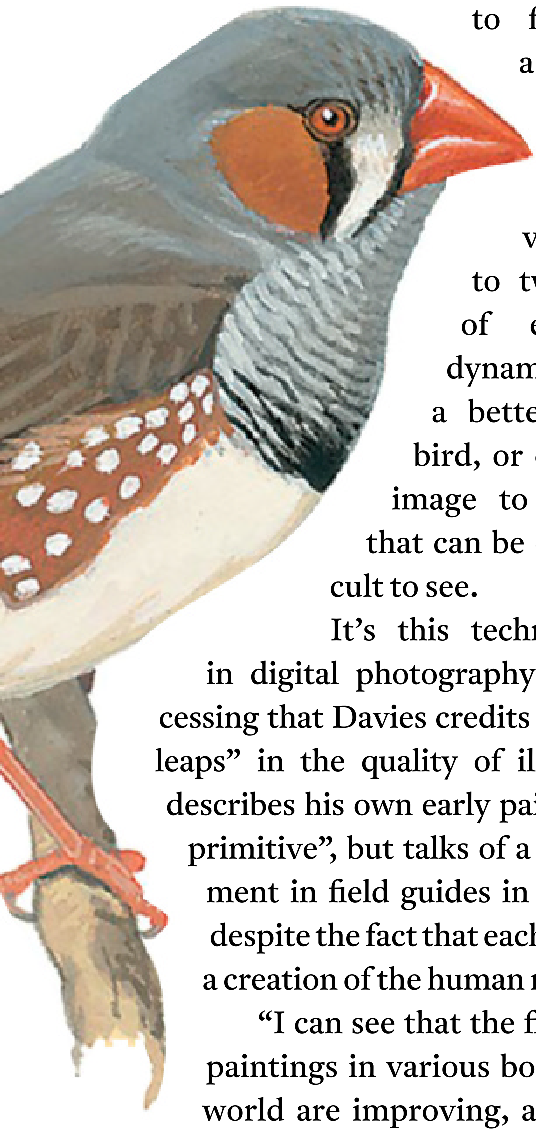


Above: scarlet-chested parrot (Neophema splendida).
Below: splendid fairywren (Malurus splendens).

> “A good illustration puts in only enough to create the essence of realism and aesthetic appeal and leaves the rest out”

But the quality and quantity of digital photography remains at the heart of the advancement of field guide illustrations. Abetting this is image-editing software such as Photoshop, which artists are now using to manipulate the photos from which they work, highlighting and drawing out the features of the birds or animals on which they want to focus. Using a RAW photo, an artist can adjust settings and various levels to tweak the likes of exposure and dynamic range to get a better look at the bird, or overexpose the image to reveal details that can be otherwise difficult to see.

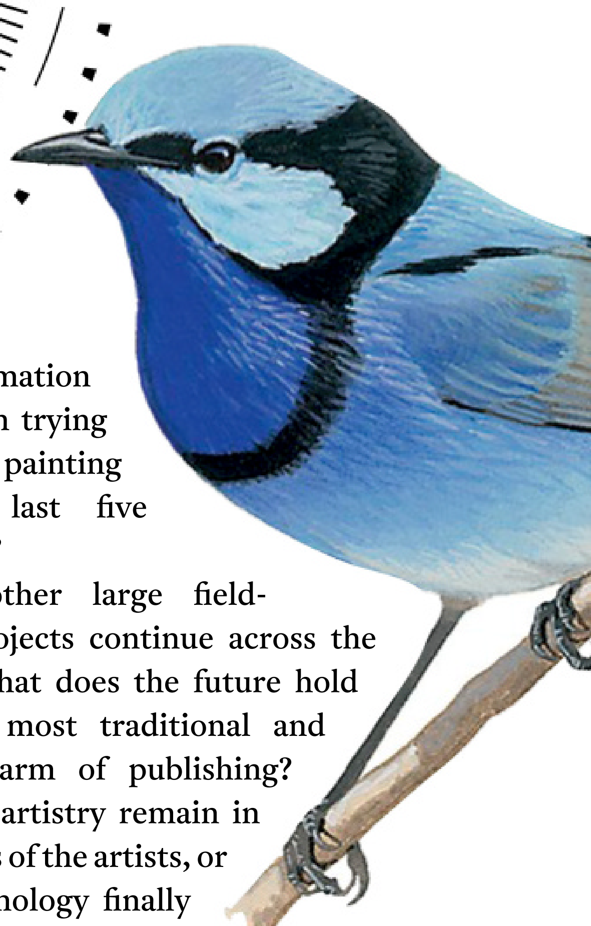
It’s this technological jump in digital photography and post-processing that Davies credits with “quantum leaps” in the quality of illustrations. He describes his own early paintings as “very primitive”, but talks of a rapid improvement in field guides in the digital age, despite the fact that each painting is still a creation of the human mind and hand.



Left: zebra finch (Taeniopygia guttata).
Below: powerful owl (Ninox strenua).

“I can see that the field illustration paintings in various books around the world are improving, and it’s because they have the digital photographs to work from, I’m sure of it,” he notes. “A lot of people say the art is just getting better, but I’m saying they’re now going ahead in quantum leaps because they’ve got better reference material to work from.

“The other advantage of that is that you can get the information you need much quicker, and there’s lots of it, so you’re not spending 95% of your time trying to source information and then trying to do the painting in the last five minutes.”



As other large field-guide projects continue across the world, what does the future hold for this most traditional and magical arm of publishing? Will the artistry remain in the hands of the artists, or will technology finally take flight to emerge as a serious competitor? Davies remains confident that the artist’s role will endure.

“I don’t see it happening, but I can’t rule it out,” he says. “I’ve got no doubt it will come, but I don’t think I can see it there on the horizon. There are subtleties [that an artist] can put in a painting that would be really labour intensive to do digitally, whereas if you just flick a brush with different strengths and different dilutions of water, you can do it quickly. Until digital gets to that, you can’t really replace it.” ◉

The Compact Australian Bird Guide is on sale now; rrp $34.99.

ANDREW BAIN is a freelance writer based in Tasmania. His last story for the magazine, on krill, appeared in Issue 89.

ALL IMAGES: JEFF DAVIES

CAN YOU ACTUALLY CATCH

KRAKENIMAGES.COM / ADOBE STOCK

Why do we yawn, and why do we yawn when another person yawns? **Ellen Phiddian** explores this most contagious of behaviours.

A YAWN?

KRAKENIMAGES.COM / ADOBE STOCK

Is it really possible to catch a yawn? Why do we do it anyway? Weirdly, for such a common behaviour there is still much that science doesn't know about yawns.

But let's explore what science *does* know…

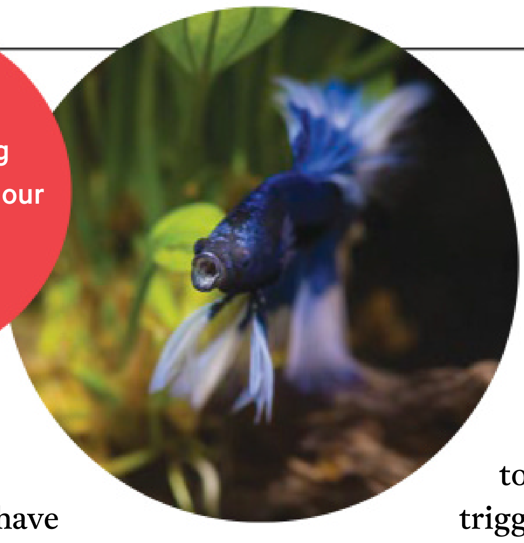
WHAT EXACTLY IS A YAWN?

A yawn is an involuntary breathing movement. It involves a jaw gaping wide and a deep, long breath. Then your muscles contract briefly, and then you exhale and shut your mouth.

This movement is not unique to people. Animals of all shapes and sizes yawn – not just mammals, but birds, reptiles and fish have all been observed yawning – or at least exhibiting "yawn-like behaviour". The Siamese fighting fish, for instance, opens its mouth in little bursts that some researchers say are yawns!

In humans, a yawn lasts about five or six seconds, but in other animals it can be shorter or longer. According to a 2021 study in *Communications Biology*, the length of the yawn is linked to brain size. The researchers analysed 1291 yawns from video footage of 101 different mammal and bird species, finding the mammals had an average yawn length of 3.4 seconds, while birds, with tiny brains, lasted 1.46 seconds on average.

Because it's so widespread, there's probably a good biological reason for yawning. Right?



Fish, including Siamese fighting fish, exhibit behaviour that resembles yawning

WHY DO WE YAWN?

In fact, we don't yet have a completely solid answer. This is partly because it's kind of hard to test yawns in a clinical setting. They're involuntary, but we all know it's possible to deliberately go through the motions of a yawn and feel similar – or stifle a yawn you feel coming on. And if you know you're supposed to be yawning for science, is that going to affect the way you yawn?

That said, there are still a few hundred studies on yawning. That's not enough to give us bulletproof facts, but it's more than enough to give us some good theories.

One idea is yawning helps to cool the brain. Ambient air is usually cooler than your body, so pulling in a lot of it in a yawn might help to cool you down. The yawn also triggers blood flowing to the brain, which cools the brain further.

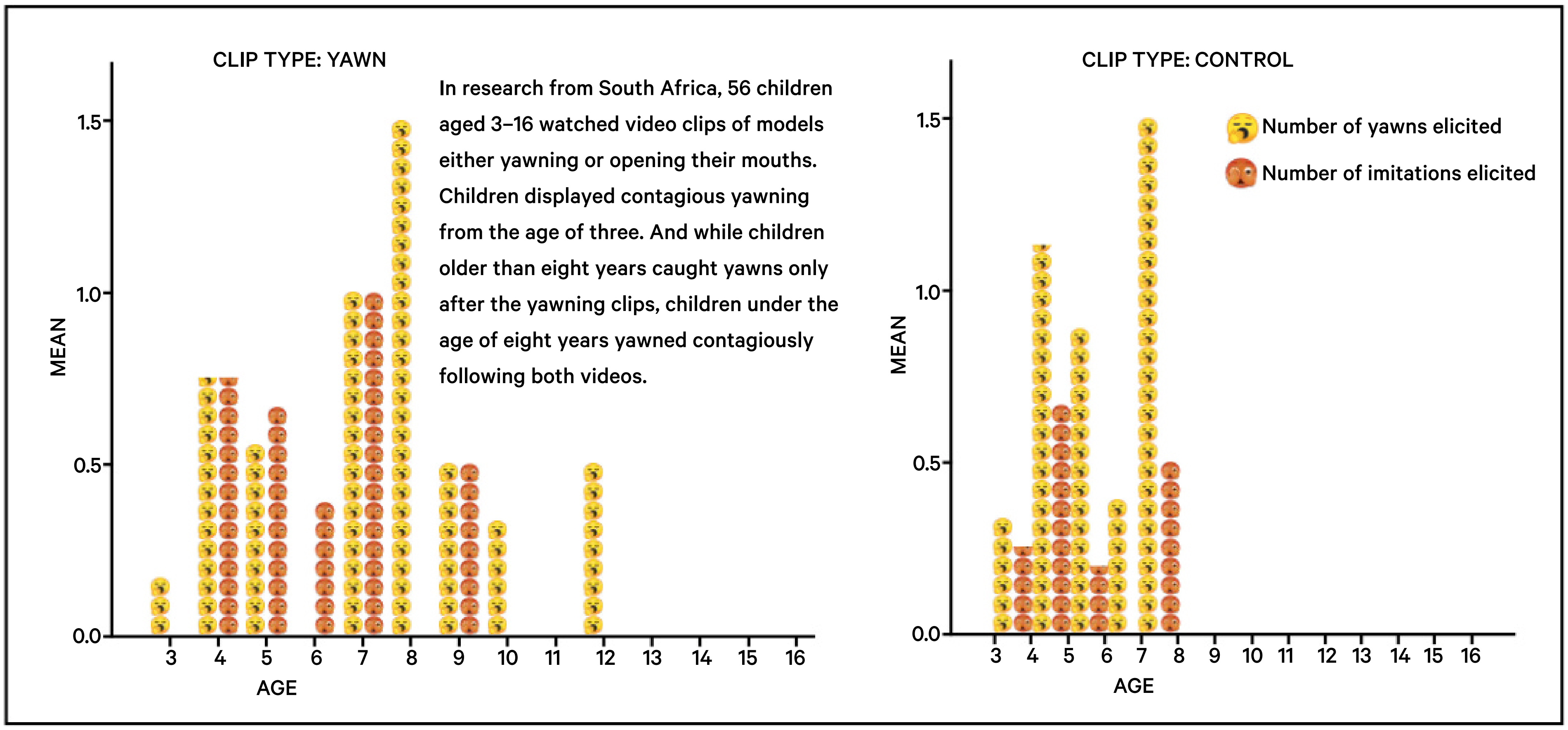
Another part of the puzzle is the time of day we yawn most – just before or after sleep. Yawning might play a role in the change from sleepy to alert, or in switching between other mental states.

Another theory suggests that ear pressure could have a role to play – and, of course, seeing someone else yawn might be a trigger.

One popular theory is that yawning increases our blood oxygen. This was actually debunked in a 1987 study, and

There's some evidence that dogs yawn in response to humans. Interestingly, a 2009 study in Animal Cognition found that dogs don't catch yawns from other dogs.

FISH: ANURAKPONG / GETTY IMAGES. DOG: RAWPIXEL.COM / ADOBE STOCK. BONOBO: FIONA ROGERS / GETTY IMAGES. COCKATOO: KAMADA KAORI / GETTY IMAGES



In research from South Africa, 56 children aged 3–16 watched video clips of models either yawning or opening their mouths. Children displayed contagious yawning from the age of three. And while children older than eight years caught yawns only after the yawning clips, children under the age of eight years yawned contagiously following both videos.

since then no-one's been able to find much evidence to support the theory.

So whatever yawning is for, it's probably not about getting more oxygen.

IS IT ACTUALLY CONTAGIOUS?

Given "why we yawn" is a tricky question, you can bet that contagious yawning is even harder to untangle.

But in fact, the contagious yawn effect is so well-established it's often used to induce yawning in yawning studies. So you're not imagining things: people definitely yawn more when they've seen someone else do it.

We're not the only social animal to "catch" a yawn. Playing videos of yawns to apes like chimpanzees, baboons and bonobos makes them yawn more. There's some evidence that dogs yawn in response to humans. Interestingly, a 2009 study in *Animal Cognition* found that dogs don't catch yawns from other dogs.

Even reading or thinking about yawning is likely to induce it: you've likely been yawning a little more while reading this article, but I'm not taking it personally.

SO WHY IS YAWNING CONTAGIOUS?

There are a few theories for this as well, and nothing completely certain.

A 2010 review in *Neuroscience & Biobehavioral Reviews* lists a few different theories.

One element is social: we often use yawning to indicate boredom or tiredness. If you notice someone else in a meeting seems bored, you might start to become disengaged yourself – and not feel as determined to suppress your own yawns.

But we know it goes deeper than that.

Mammals yawn for an average of 3.4s, while birds take a speedy 1.46s

MRI scans have shown that watching someone else yawn activates regions in the brain linked to imitation, empathy, and social behaviour. But none of this research is conclusive.

Another theory suggests there's an evolutionary advantage to yawning. If one person yawns because they're ready to go to sleep, that indicates to the rest of the group that it's safe to sleep. Alternatively, rousing yawns can enhance a group's vigilance or coordinate behaviour.

We're getting into very speculative territory here. There are likely some social factors to yawning, some biological, and some neurological ones – and some that are a combination. ◉

ELLEN PHIDDIAN is a chemistry graduate and science journalist at *Cosmos*. In the last issue, Ellen unpacked sausage ingredients.

CITATION: HOOGENHOUT M, VAN DER STRAATEN K, PILEGGI LA, MALCOLM-SMITH S (2013) YOUNG CHILDREN DISPLAY CONTAGIOUS YAWNING WHEN LOOKING AT THE EYES.

Hear *Cosmos* journalists explain all of life's big and small questions on our new weekly podcast: *Huh? Science Explained*

WHERE IN THE COSMOS?

Send us a pic of where you're reading *Cosmos* to win a copy of *Best Australian Science Writing 2022*!

SCIENCE AT SEA

"Dear Cosmos," writes Wendy Scott from Kenmore East in Queensland, "I am on the balcony of the *Coral Princess* soaking up the winter sun before setting sail." We'd love to see where you're reading! Please send us a shot of your special science place: **contribute@cosmosmagazine.com**.

GUESS WHO?

QUESTION

Whose Principle? Decode where t = ⧫

■♓♍□●♋⬧ ⬧⧫♏■□

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HINT:

He was a Danish scientist whose principles were published in 1669.

MIND GAMES

Who Said?

NO.22

"It is a little appreciated fact that most of the animals in our ocean make light." (5,6)

	1	2	3	4	5	6	7	8	9	10	11
I	■		■		■			■		■	
II			■								
III											
IV											
V											
VI											
VII											
VIII											
IX				■		■					
X				■		■	■		■		

INSTRUCTIONS

Answers to each of the clues in columns 1 to 11.
Row VII reveals the answer.

CLUES AND COLUMNS

1 What is the simplest alkyne hydrocarbon, consisting of two hydrogen atoms and two carbon atoms connected by a triple bond? (9)
2 In plural, what object is made from four triangular sides? (10)
3 What can be 'gold', 'ground', 'fan' or 'a miner'? (8)
4 Which branch of ornithology studies birds' eggs? (8)
5 In Suffolk, at which archaeological site was an Anglo-Saxon ship discovered? (6,3)
6 Which controversial figure and son of a Lutheran minister recorded the language and traditions of the central Australian people and published Songs of Central Australia (1971)? (8)
7 Usually a result of alcoholism or hepatitis, what name is given in medicine to the chronic liver disease marked by the degeneration of cells, inflammation, and thickening tissue? (9)
8 At which university is the Cavendish Laboratory? (9)
9 Which part of an electrical system emits or collects electric charges? (9)
10 One of the few constellations mentioned in the Bible, what is the English name for the group of stars containing the Big Dipper? (5,4)
11 What are the prokaryotic microorganisms which consist of a single cell lacking a nucleus and contain DNA in a single circular chromosome? (10)

Cosmos Codeword

NO.22

9	14	24	14	25 S	7	16	11	■	23	1	14	24	16	15
24	■	14	■	16	■	24	■	19	■	10	■	1	■	11
11	9	7	16	5	13	11	■	24	11	11	19	7	11	24
19	■	10	■	10	■	26	■	5	■	23	■	10	■	5
14	8	6	14	2	25	■	12	1	4	1	8	14	24	■
16	■	14	■	■	■	21	■	4	■	14	■	16	■	14
5	25	16	11	5	9	14	16	18	■	8	2	7	10	4
24	■	11	■	21	■	10	■	16	■	■	■	5	■	24
■	21	24	14	20	14	19	5	■	10	1	14	10	22	11
14	■	■	■	7	■	7	■	17	■	24	■	■	■	11
13	7	25	22	5	10	22 C	11	7	20	11	■	17	14	19 D
9	■	22	■	1	■	5	■	3	■	16	■	14	■	■
11	14	24	■	25	16	5	13	14	22	18	14	22	18	11
24	■	1	■	8	■	16	■	16	■	24	■	11	■	10
11	13	21	24	2	5	■	24	11	19	14	22	16	11	19

Codeword requires inspired guesswork. It is a crossword without clues. Each letter of the alphabet is used and each letter has its own number. For example, 'A' might be 6 and 'G' might be 23.

Through your knowledge of the English language you will be able to break the code. We have given you three letters to get you started.

1	2	3	4	5	6	7	8	9	10	11	12	13
14	15	16	17	18	19	20	21	22	23	24	25	26

ALL PUZZLES DESIGNED
AND COMPILED BY
SNODGER.COM.AU

It Figures

NO.22

	1	2	3	4
A				
B				
C				
D				

INSTRUCTIONS

Using the clues below place the numbers 1 to 16 correctly in the grid. How many clues do you need?

LEVEL 1 – CHIEF SCIENTIST

1 The highest four composite numbers share either a row or column containing only their factors.
2 The product of the last three numbers in Column 4 is equal to the first.
3 The sum of numbers is Row A is 55.
4 The product of the three ascending numbers beginning Row C is 720.
5 The sum of the first and last numbers in the column immediately right of the one containing the 12 is 27.

LEVEL 2 – SENIOR ANALYST

6 The largest number is in the opposite corner to the smallest.
7 The product of the last two numbers in Column 2 is 63.

LEVEL 3 – LAB ASSISTANT

8 The last number in Row B is half of the number to its left.

SOLUTIONS: COSMOS 95

CODEWORD

N	U	M	B	E	R	■	B	L	I	Z	Z	A	R	D
E	■	A	■	X	■	E	■	U	■	I	■	P	■	R
G	E	C	K	O	■	X	Y	L	O	P	H	O	N	E
A	■	H	■	S	■	C	■	L	■	■	■	S	■	A
T	R	I	C	K	L	E	■	E	Q	U	A	T	O	R
I	■	N	■	E	■	S	■	D	■	N	■	R	■	Y
V	I	E	W	L	E	S	S	■	F	R	E	O	N	■
E	■	R	■	E	■	■	■	J	■	E	■	P	■	I
■	D	Y	S	T	O	P	I	A	■	A	P	H	I	D
T	■	■	■	O	■	A	■	C	■	L	■	E	■	I
W	E	B	I	N	A	R	■	K	N	I	T	■	G	O
E	■	A	■	■	■	A	■	P	■	S	■	K	■	L
L	A	R	V	A	■	G	H	O	S	T	L	I	K	E
V	■	G	■	S	■	O	■	T	■	I	■	W	■	C
E	L	E	P	H	A	N	T	■	S	C	R	I	P	T

1 P	2 C	3 F	4 A	5 G	6 K	7 E	8 Q	9 L	10 U	11 N	12 Z	13 Y
14 D	15 R	16 W	17 O	18 B	19 M	20 X	21 J	22 I	23 V	24 S	25 H	26 T

IT FIGURES

5	14	7	13
10	2	8	16
11	4	1	9
15	12	6	3

WHO SAID?

Yann Martel

Canadian writer Yann Martel is a Fellow of the Royal Society of Literature and the acclaimed author of international best-seller *Life of Pi*.

A	■	■	O	■	T	M	■	M	P
M	F	T	R	■	I	E	O	E	L
E	O	O	O	B	T	T	M	I	A
T	R	P	G	R	I	E	E	S	N
H	N	O	E	U	C	O	N	S	U
Y	A	N	N	M	A	R	T	E	L
S	X	Y	I	B	C	■	U	N	A
T	■	M	C	Y	A	■	M	■	E

WHOSE LAW?

ANSWER:

When the pressure on a sample of a dry gas is held constant, the Kelvin temperature and the volume will be in direct proportion.
Jacques Charles

Abigail Shaughnessy

VISION MARINE BIOLOGIST

COURTESY OF ABIGAIL SHAUGHNESSY

When we speak to marine biologist Abigail Shaughnessy, she's on Lizard Island, surrounded by the Great Barrier Reef in North Queensland. She spends her mornings out on the reef catching damselfish to study their vision.

"In the afternoon, I sit in the dark and do some electrophysiology,' she says. "The less charming side, I suppose."

Electrophysiology is a test where a flash of light directed at the eye can tell you how well the visual nerve pathway sends electrical signals for vision.

It's commonly used by optometrists to test human eyes, but Shaughnessy is undertaking her PhD by doing the same experiment on damselfish's eyes, to investigate tiny vision changes at different times of the year.

"I'm currently doing a chapter for my PhD, looking at what effect the seasonal shifts between winter and summer has on the vision of the fish," she says.

"They've got a particularly plastic visual system, and we know from a molecular investigation that they're shifting between summer and winter."

She is part of the sensory neurobiology group at the University of Queensland, led by Professor Justin Marshall. The team has so far uncovered how fish discriminate colour, discovered the immensely complex vision of the mantis shrimp, and helped map the huge variety of vision in sea life.

But Shaughnessy suggests that more work needs to be done in this space.

"There's often difficulty with the marine world, where a lot of genetic approaches have been focused on model systems," she says. "So often people use zebrafish and then try to do these experiments and extrapolate out of that."

> "In the afternoon, I sit in the dark and do some electrophysiology. The less charming side, I suppose."

Because zebrafish are a freshwater fish – and best used for their see-through embryos – they're not particularly relevant for those doing ocean research. Instead, the sensory neurobiology group are trying to create a marine fish model organism to help plug this gap.

READ MORE ABOUT THE MYSTERIES OF SIGHT BETWEEN SPECIES ON PAGE 56.

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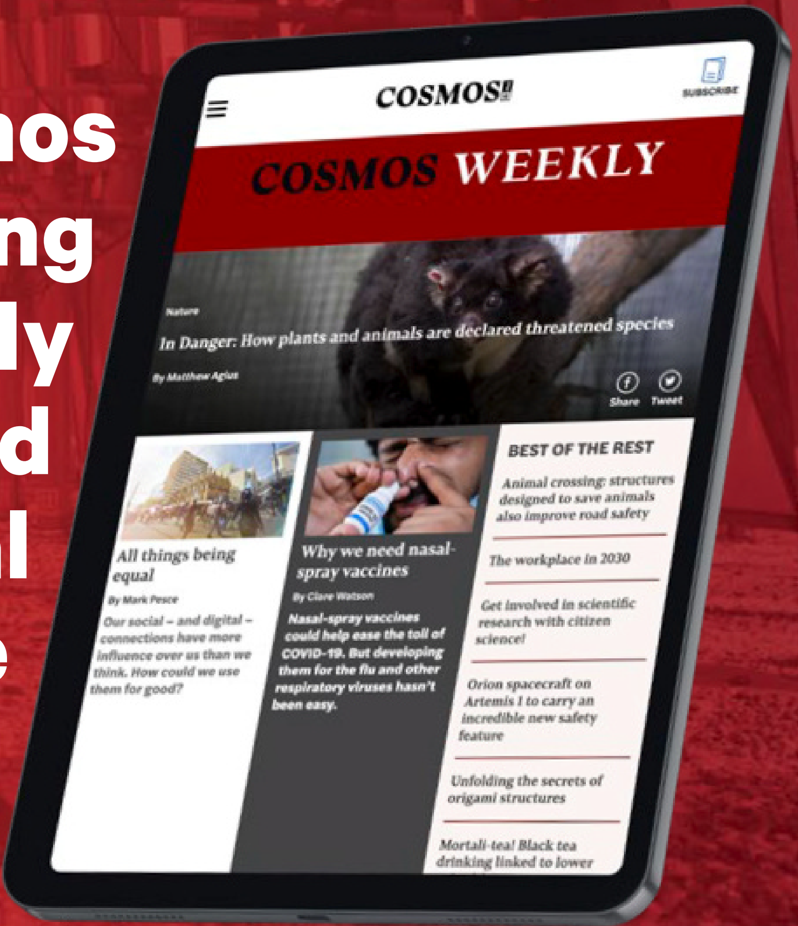

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